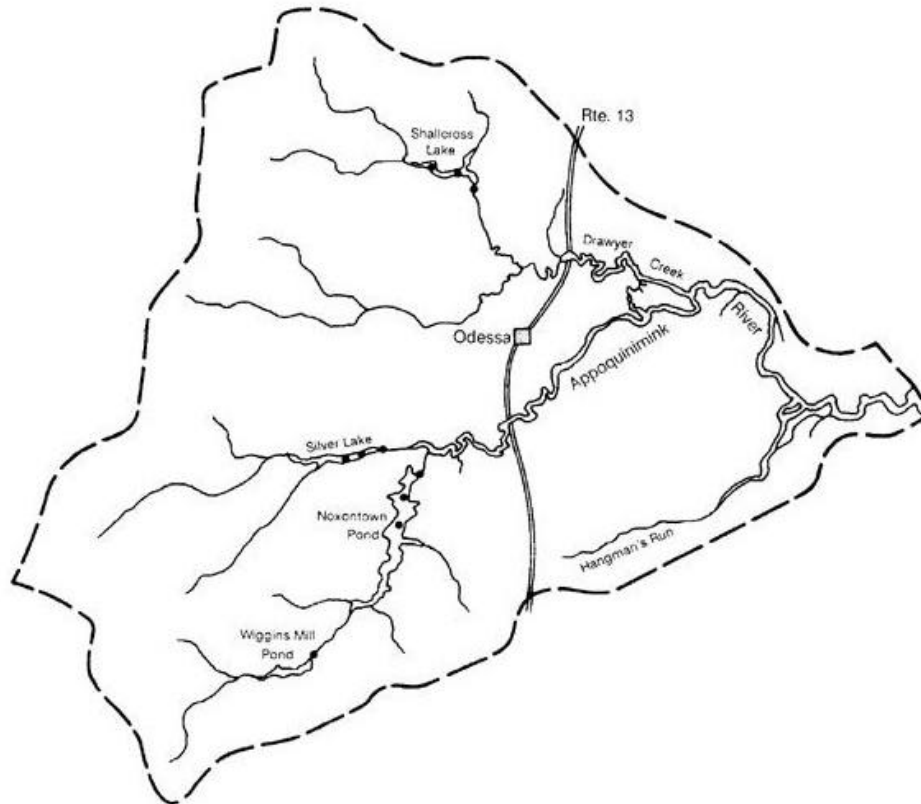


**Appendix B: DNREC's Technical Analysis for the Proposed
Appoquinimink River TMDLs - October 2001.**

Technical Analysis for the Proposed Appoquinimink River TMDLs - October 2001



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EXECUTIVE SUMMARY

Section 303(d) of the Clean Water Act (CWA) requires States to identify and establish a priority ranking for waters in which existing pollution controls are not sufficient to attain and maintain State water quality standards, establish Total Maximum Daily Loads (TMDLs) for those waters, and periodically submit the list of impaired waters (303(d) list) and TMDLs to the United States Environmental Protection Agency (EPA).

Due to their high nutrient concentrations and/or low dissolved oxygen levels, the Delaware Department of Natural Resources and Environmental Control (DNREC) has identified and included in the States 1996, 1998, and/or proposed 2000 303(d) lists the following segments of the Appoquinimink River and its tributaries and ponds as impaired:

- Lower Appoquinimink River (DE010-001-01)
- Upper Appoquinimink River (DE010-001-02)
- Drawyer Creek (DE010-001-03)
- Wiggins Mill Pond to confluence with Silver Lake (DE010-002-01)
- Deep Creek to confluence with Silver Lake (DE010-002-02)
- Noxontown Pond (DE010-L01)
- Silver Lake (DE010-L02)
- Shallcross Lake (DE010-L03)

A court-appointed Consent Decree (C.A> No. 960591, D. Del 1996) requires that the Appoquinimink TMDL be established by December, 2001.

The proposed Appoquinimink River TMDL is based on an assessment of the water quality condition of the Appoquinimink River and its tributaries and ponds during design conditions under various levels of point and nonpoint source loading levels. A calibrated and verified hydrodynamic water quality of the Appoquinimink River and its tributaries and ponds model was used as an assessment tool. The Appoquinimink River Model was developed using extensive hydrological and water quality data collected from 1991 through 1993 and from 1997 through 2000.

Considering the results of the assessment, DNREC has determined that in order to meet the State's water quality standards and targets, the point and nonpoint source nutrients loads (nitrogen and phosphorous) and oxygen consuming compounds (CBOD5) within the watershed should be reduced as described in Table ES-1. The proposed Appoquinimink River TMDL includes a Load Allocation (LA) for nonpoint sources and a Waste Load Allocation (WLA) for point source discharges. The margin of safety for the Appoquinimink River TMDL is considered to be implicit as the result of the consideration of conservative assumptions made during the TMDL analysis.

Table ES-1 Proposed TMDL Loads for the Appoquinimink Watershed

Source	Flow (mgd)	Total N (lb/d)	Total P (lb/d)	CBOD5 (lb/d)
Waste Load Allocation (WLA) for Point Source: MOT	0.5	10.4	2.1	34.8
Load Allocation (LA) for Nonpoint Sources	-	334.1	18.0	-
Proposed TMDL Total Loads	-	344.5	20.1	34.8

1. Introduction/Background

Under Section 303(d) of the Clean Water Act (CWA), States are required to identify and establish a priority ranking for waters in which existing pollution controls are not sufficient to attain and maintain State water quality standards, establish Total Maximum Daily Loads (TMDLs) for those waters, and periodically submit the list of impaired waters (303(d) list) and TMDLs to the United States Environmental Protection Agency (EPA). If a State fails to adequately meet the requirements of section 303(d), the CWA requires the EPA to establish a 303(d) list and/or determine TMDLs for that State.

In 1996, the EPA was sued under Section 303(d) of the CWA concerning the 303(d) list and TMDLs for the State of Delaware. The suit maintained that Delaware had failed to fulfill all of the requirements of Section 303(d) and the EPA had failed to assume the responsibilities not adequately preformed by the State. A settlement in the suit was reached and the Delaware Department of Natural Resources and Environmental Control (DNREC) and the EPA signed a Memorandum of Understanding (MOU) on July 25, 1997. Under the settlement, DNREC and the EPA agreed to complete TMDLs for all 1996 listed waters on a 10-year schedule.

In the Appoquinimink River watershed, a number of river segments, tributaries and ponds have been included on the State's Clean Water Action Section 303(d) List of Waters needing Total Maximum Daily Loads (Table 1-1, Figure 1-1). TMDLs need to be established for dissolved oxygen, nutrients (nitrogen and phosphorus) and bacteria concentrations.

The development of a TMDL for a particular water body typically requires the application of a receiving water model, which simulates the movement and transformation of pollutants through the water body. This can be used to predict water quality conditions under different pollutant loading scenarios to determine the loading scenario that will allow ambient conditions to meet water quality standards.

In 1998, EPA Region III, in cooperation with DNREC adopted a TMDL for the main stem of the Appoquinimink River (DE010-001-01, DE010-001-02) using a DYNHYD-WASP model. This TMDL expanded the Phase 1 TMDL developed by DNREC in 1992. The focus of the 1998 TMDL was to address water quality impairments due to low dissolved oxygen concentrations violating the daily standard of 5.5 mg/L. The TMDL called for reductions in phosphorus, carbon (carbonaceous biochemical oxygen demand [CBOD5]) and nitrogen [ammonia, and organic nitrogen] from both point and non-point sources.

TMDLs are required for the tributaries and ponds within the Appoquinimink River Watershed prior to December 2001, therefore, the 1998 DYNHYD-WASP model was expanded to include it's tributaries and ponds (DE010-001-03, DE010-002-01, DE010-002-02, DE010-L01, DE010-L02, DE010-L03). They include: Drawyer Creek, Deep Creek, Shallcross Lake, Silver Lake, Noxontown Lake and Wiggins Mill Pond (Figure 1-1). The expanded model (ARM1) will be built upon the TMDLs developed in 1998.

Table 1-1 Appoquinimink River Watershed Segments listed on the Proposed 2000 303(d) List

Waterbody ID (Total Size)	Watershed Name	Segment	Description	Size Affected	Pollutant(s) and/or Stressors	Probable Sources	Year Listed	Target Date for TMDL
DE010-001-01 (7.1 miles)	Appoquinimink River	Lower Appoquinimink River	Saline Tidal Reach, excluding Hangman's Run	7.1 miles	Nutrients, DO	PS, NPS	1996	Established 1998 (for Nutrients and DO)
					Bacteria, PCBs, Dioxins	NPS	2000	2006 (for Bacteria)
								2011 (for PCBs, Dioxin)
DE010-001-02 (6.1 miles)	Appoquinimink River	Upper Appoquinimink River	Freshwater Tidal Reach	6.1 miles	Nutrients, DO	PS, NPS	1996	Established 1998 (for Nutrients and DO)
					Bacteria	PS, NPS	2000	2006
					PCBs, Dioxins	NPS	2000	2011
DE010-001-03 (19.5 miles)	Appoquinimink River	Drawyer Creek	From the headwaters of Drawyer Creek to the confluence with the Appoquinimink River, including Shallcross Lake	8.2 miles	Bacteria, Nutrients, DO	NPS	1996	2001 (for Nutrients and DO)
			Tributary of Drawyer Creek--from the confluence of the headwaters to the confluence with the mainstem	2.30 miles	Biology and Habitat	NPS	1998	2006 (for Bacteria)
			Western tributary of the headwaters of Drawyer Creek to its confluence	2.20 miles	Habitat	NPS	1998	2011
DE010-001-03 (19.5 miles)	Appoquinimink River	Drawyer Creek	Tidal Portion		PCB,DDT	NPS	2000	2011
DE010-002-01 (3.4 miles)	Appoquinimink River	Wiggins Mill Pond to confluence with Silver Lake	From the headwaters of Wiggins Mill Pond to the confluence with Noxontown Pond	3.4 miles	Bacteria, DO	NPS	1996	2001 (for DO)
					Nutrients	NPS	2000	2006 (for Bacteria)
			From the confluence of the headwaters of Wiggins Mill Pond to the confluence with Noxontown Pond	1.62 miles	Biology	NPS	1998	2001
								2011

Waterbody ID (Total Size)	Watershed Name	Segment	Description	Size Affected	Pollutant(s) and/or Stressors	Probable Sources	Year Listed	Target Date for TMDL
DE010-002-02 (4.4 miles)	Appoquinimink River	Deep Creek to confluence with Silver Lake	From the headwaters of Deep Creek to confluence with Silver Lake, excluding Silver Lake	2.4 miles	DO	NPS	1996	2001
					Bacteria, Nutrients	NPS	2000	2001 (for Nutrients)
								2006 (for Bacteria)
			First western tributary after the headwaters of Silver Lake	1.98 miles	Biology	NPS	1998	2011
			Deep Creek.-- from the confluence of the headwaters to Appoquinimink River	1.84 miles	Biology	NPS	1998	2011
DE010-L01 (158.6 acres)	Appoquinimink River	Noxontown Pond	Pond southwest of Odessa	158.6 acres	Bacteria, Nutrients	NPS	1998	2001 (for Nutrients)
								2006 (for Bacteria)
DE010-L02 (38.7 acres)	Appoquinimink River	Silver Lake	Lake adjacent to Middletown, below Deep Creek	38.7 acres	Bacteria, Nutrients	NPS	1996	2001 (for Nutrients)
					PCB, Dieldrin, DDT, Dioxin	NPS	2000	2006 (for Bacteria)
DE010-L03 (43.1 acres)	Appoquinimink River	Shallcross Lake	Lake above Drawyer Creek	43.1 acres	Bacteria, Nutrients	NPS	1996	2001 (for Nutrients)
								2006 (for Bacteria)

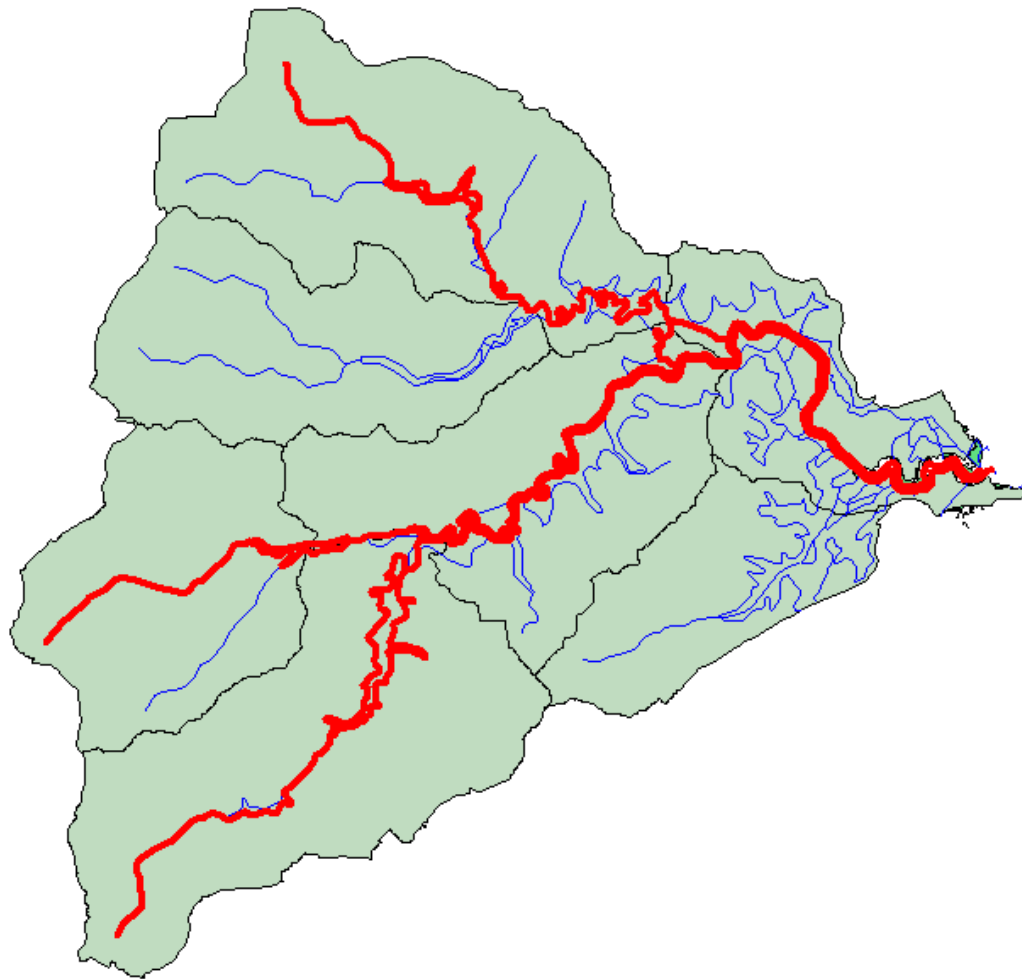


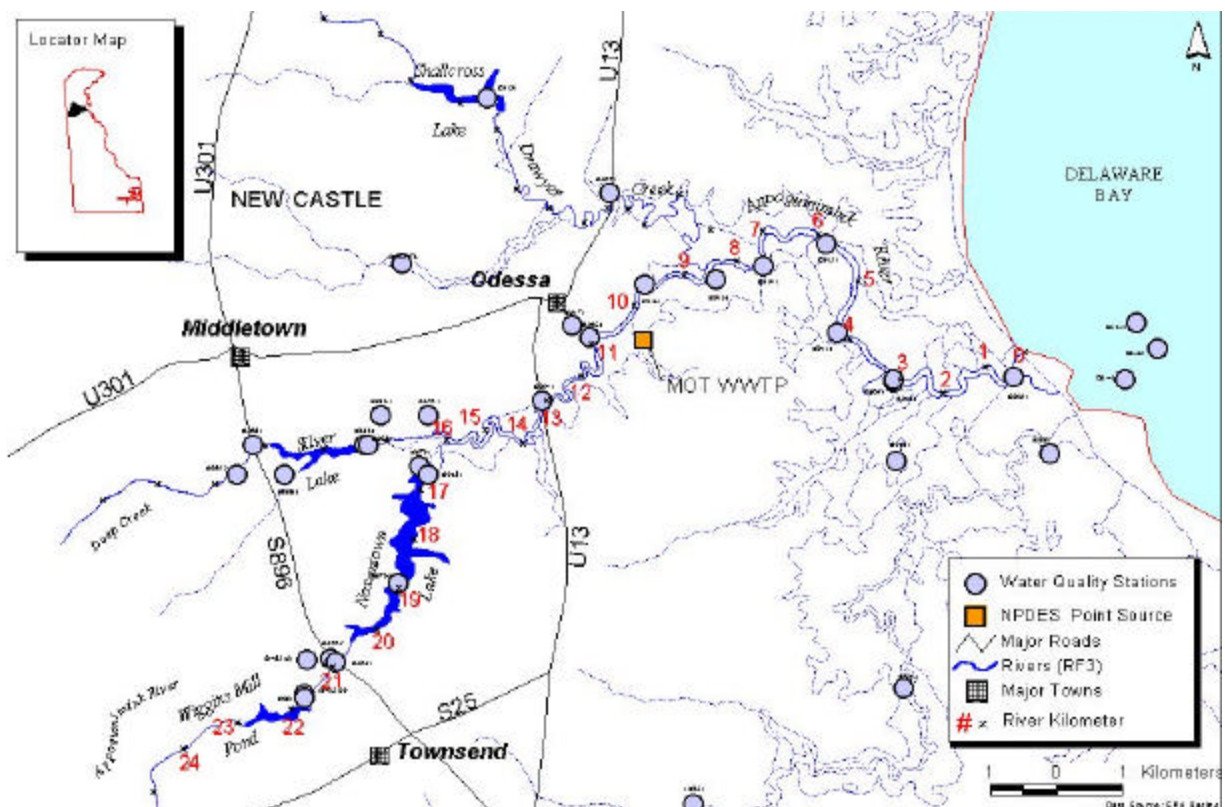
Figure 1-1 Segments within the Appoquinimink River Watershed included in the 1998 303(d) Listing

2. The Appoquinimink River Watershed

The Appoquinimink River watershed is located in the flat coastal plain of eastern Delaware (New Castle County). The watershed is approximately 47 square miles and can be described as primarily agricultural with three residential/urban centers: Middletown, Odessa and Townsend. The land is generally characterized as flat to gently sloping, which is typical of the coastal plain.

The Appoquinimink River system consists of three main branches. Moving south to north, it includes: the Appoquinimink River (Wiggins Mill Pond and Noxontown Lake); Deep Creek (Silver Lake); and Drawyer Creek (Shallcross Lake). The ponds and lakes included in the Appoquinimink River Watershed are typically shallow, man-made ponds maintained by dams.

The system is tidal up to the outlet dams of Noxontown Lake on the Appoquinimink River main stem, Silver Lake on Deep Creek, and the Drawyer Creek's confluence with the Appoquinimink River. The salinity from Delaware Bay typically extends past the Drawyer Creek - Appoquinimink confluence at river kilometer (Rkm) 8.5. The only point source within the system is the Middletown-Odessa-Townsend wastewater treatment plant (MOT WWTP) located at Rkm 10 which primarily uses spray irrigation to dispose of its effluent but may occasionally discharge into the surface waters of the Appoquinimink River.



2.1. Designated Uses

Section 10 of the State of Delaware Surface Water Quality Standards, as amended August 11, 1999, specifies the following designated uses for the waters of the Appoquinimink River watershed:

1. Primary Contact Recreation
2. Secondary Contact Recreation
3. Fish, Aquatic Life, and Wildlife
4. Industrial Water Supply
5. Agricultural Water Supply (freshwater segments)

2.2. Applicable Water Quality Standards

The following sections of the State of Delaware Surface Water Quality Standards, as amended August 11, 1999, provide specific narrative and/or numeric criteria concerning the waters of the Appoquinimink River Watershed:

1. Section 3: General guidelines regarding Department's Antidegradation policies
2. Section 7: Specific narrative and numeric criteria for controlling nutrient overenrichment in waters of the State
3. Section 9: Specific narrative and numeric criteria for toxic substances
4. Section 11: General water criteria for surface waters of the State

According to Section 11 and 7 of the Standards, the following water quality criteria are applicable to fresh and/or marine waters of the Appoquinimink River:

A. Dissolved Oxygen (DO)

- a. 5.5 mg/L daily average (from June through September) for fresh waters. Fresh waters are defined as those having a salinity of less than 5 parts per thousand
- b. 5.0 mg/L daily average (from June through September) for marine waters. Marine waters are defined as those having a salinity of equal to or greater than 5 parts per thousand.
- c. 4.0 mg/L minimum at any time of both fresh and marine waters.

Based on the salinity data (Figure 2-2), all portions of the Appoquinimink River and its tributaries are considered to be fresh water because the minimum salinity levels are less than 5 ppt.

B. Enterococcus Bacteria

- a. For fresh waters, the geometric average of representative samples should not exceed 100 colonies/100 mL.

C. Nutrients

- a. Section 7 of the Standards uses a narrative statement for controlling nutrient overenrichment of the State's surface waters. It states; "*Nutrient overenrichment is recognized as a significant problem in some surface waters of the State. It shall be the policy of this Department to minimize nutrient input to surface waters from point sources and human induced nonpoint sources. Thy types of, and need for, nutrient controls shall be established on a site-specific basis. For lakes and ponds, controls shall be designed to eliminate overenrichment.*"

In the absence of numeric nutrient criteria, DNREC has decided upon threshold levels of 3.0 mg/L for total nitrogen and 0.1 mg/L for total phosphorous in determining whether a stream should be included on the State's list of impaired waters (303(d) lists). These threshold levels are generally accepted by the scientific community to be an indication of overenriched waters.

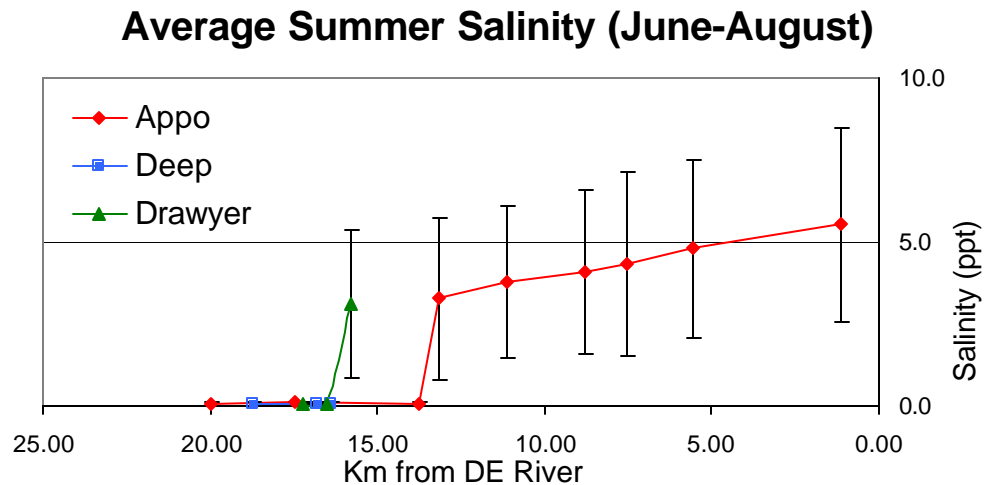


Figure 2-2 Summer Salinity within the Appoquinimink River Watershed ('97-'00 data)

3. Development of the Appoquinimink River WASP5 Model

HydroQual Inc. was contracted by the Delaware DNREC to expand, calibrate, and validate the ARM0 model to include the additional sections within the watershed listed on the 303(d) list (Section 1). The following sections are excerpts from their report, “The Appoquinimink River Watershed TMDL Model”, delivered in June, 2001.

3.1. Previous modeling Study

The “TMDL Model Study for the Appoquinimink River, Delaware” was issued in May 1993 and included tidal hydrodynamics using DYNHYD5 (hydrodynamic submodel included in WASP5). The DYNHYD5 model of the Appoquinimink River was an advance over the earlier modeling study (Phase I TMDL, DNREC 1992), which simulated the movement of water in the estuary as steady state and tidally averaged conditions.

The Appoquinimink River was segmented into 27 nodes or junctions and 26 connecting channels. Figure 3-1 shows the WASP segmentation of the previous modeling study (ARM0). For each segment the surface area and average depth at (mean sea level) were determined for input to the DYNHYD5 hydrodynamic sub model. For each channel, the depth, length, cross-sectional area, downstream (positive flow) direction, and Manning’s ‘n’ roughness coefficient were estimated. The channel geometries (depth and width) were estimated from data measured by the USGS at ten stations along the Appoquinimink River. The geometries for segments between the measured cross-sections were estimated by interpolation.

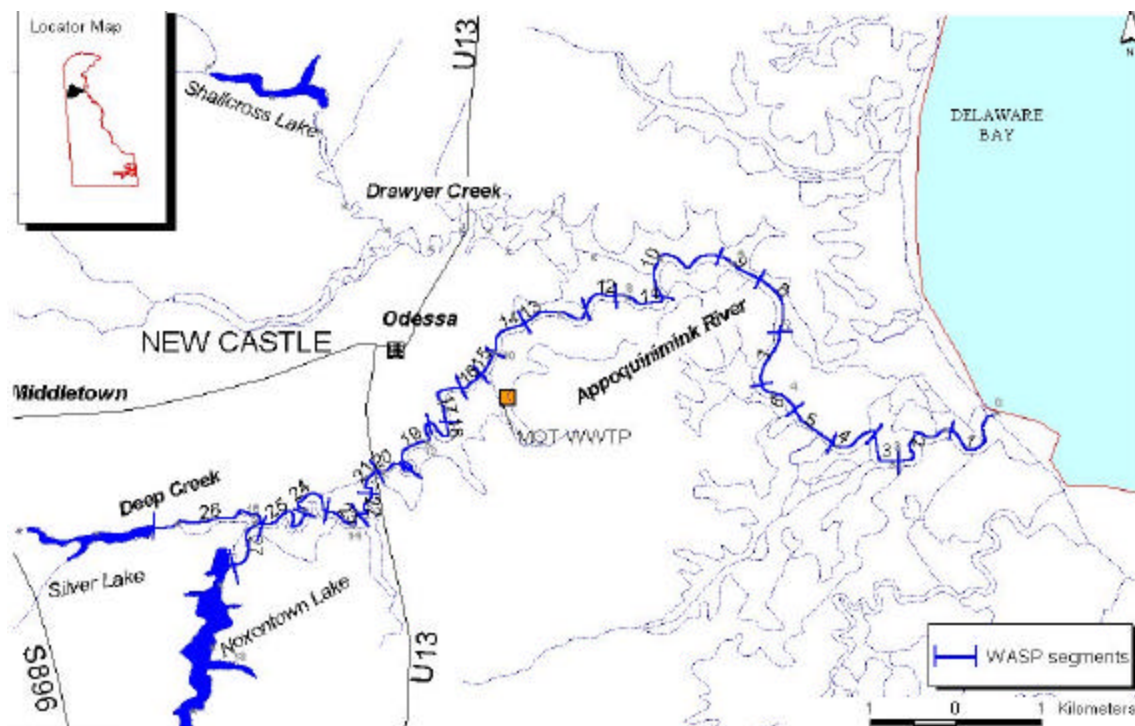


Figure 3-1 ARM0 WASP Segmentation

Boundary tides at the mouth of the Appoquinimink River were estimated from National Oceanic and Atmospheric Administration (NOAA) tide predictions using Reedy Point as the reference station. The times and heights of the high and low tides were then corrected to Liston Point which is about 3 miles south of the mouth of Appoquinimink River. The high and low tides over the period August 11 to October 19, 1991, were used as the boundary forcing condition in the model. Tributary flows in the model were set to constant values for the following locations for the August-October period.

Noxontown Pond	4.0 cfs	Model Junction 26
Silver Lake	4.0 cfs	Model Junction 27
Drawyer Creek	13.5 cfs	Model Junction 11

These flows were estimated based on the drainage area of each sub watershed and flows measured by a nearby USGS gage on Morgan Creek near Kennedyville, Maryland.

3.2. River Geometry

3.2.1 Hydrodynamic Data

3.2.1.1. Geometry

Expanding the existing Appoquinimink River Model (ARM0) to include upstream river reaches and lakes required additional data collection. Combined with the existing bathymetry and geometry data, the new data provided the basis for the expanded model grid. The river geometry data used to set up the new model framework came from four primary sources:

- 1) 1993 DYNHYD5 Model: Hydrodynamic model setup which included river geometry for the Appoquinimink River. The 1993 river geometry data was used as the basis for extending the existing hydrodynamic data. Depths, widths, flows and roughness coefficients values for the ARM0 were used to assign the values to the new tributaries.
- 2) RF3 files: United States Environmental Protection Agency (USEPA) - Reach File, Version 3 (RF3) data for rivers. RF3 data for rivers was used for the model segmentation. This data also provided the location and lengths of Drawyer Creek and Deep Creek.
- 3) USGS Topographic Maps: United States Geological Survey (USGS) 7.5 minute topographic map for elevation data and river length. The USGS topographic map of the area was used to estimate widths of Drawyer and Deep Creeks as well as the reaches of the Appoquinimink River upstream of the Noxontown Pond.
- 4) DNREC Survey - May 2000: DNREC collected geometry data during the Acoustic Doppler Current Profiler (ADCP) survey conducted at several sites along the Appoquinimink River on May 9, 2000. The lengths and widths collected during the ADCP survey were used in the hydrodynamic model setup (Table 3-1 , Table 3-2, Figure 3-2, Figure 3-3, Figure 3-4).

Table 3-1 Cross Sectional Data (5/9/2000)

Station	Width (m)	Depth (m)	DYNHYD Segment Number
1	94.35	4.6	2
2	74.78	4.1	6
3	97.32	2.72	8, 9
4	64.9	4.8	11
5	62.6	2.11	48
6	47.1	3.37	14
7	51.1	3.0	17

DNREC also provided geometry data for the 4 ponds/lakes located in the Appoquinimink River Watershed. These data are presented in Table 3-2 and were also used in the model segmentation setup.

Table 3-2 Physical Characteristics of the Ponds

Pond	Surface Area (acres)	Dam Height (ft)
Noxontown Pond	158.6	6
Shallcross Lake	43.3	8
Wiggins Mill Pond	21.2	15
Silver Lake	38.2	10

3.2.1.2. Flow Data

The 1993 DYNHYD5 model (ARM0) provided the flow data in the segments of the Appoquinimink River main stem. This flow output data was used to calibrate the expanded DYNHYD5 model (ARM1). The freshwater inflows, roughness coefficients and river geometry were adjusted to fit the 1993 flow data.

3.2.1.3. Tide Data

Tidal elevation data at the boundary was obtained from the 1993 DYNHYD5 model. Two periods of continuous data were available for the boundary:

- 1) August through October 1991 (~ 2 months)
- 2) May through July 1991 (~ 3 months)

The tidal elevation data at the Delaware River boundary is presented in Figure 3-5. During these two periods the tidal elevations, ranged from approximately -1 to 1 meter with a maximum tidal range of approximately 2 meters.

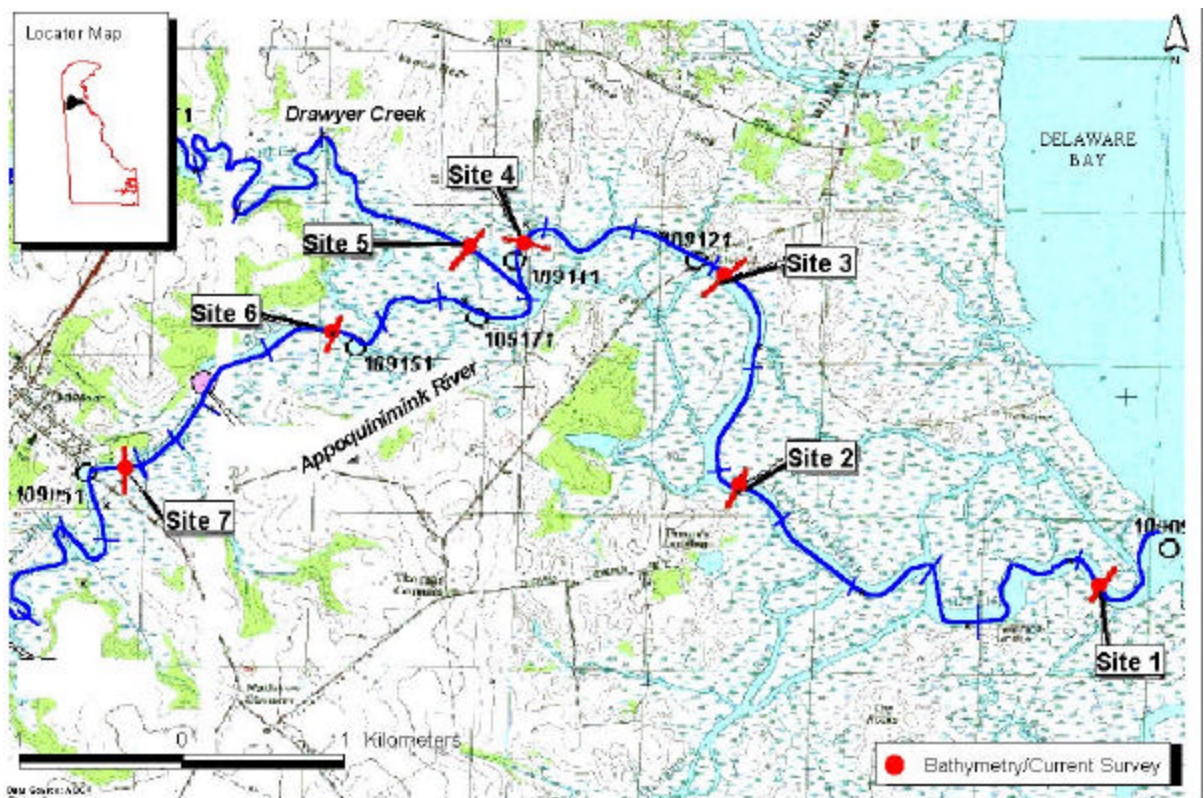


Figure 3-2 Bathymetry Survey (5/9/2000)

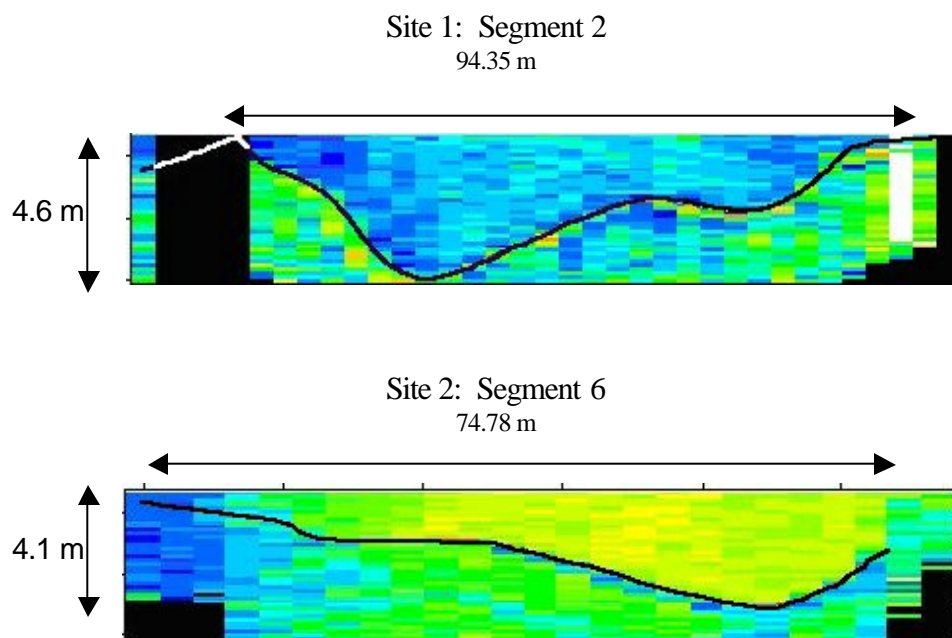


Figure 3-3 Cross Sectional Data –Sites 1 & 2 (ADCP Survey)

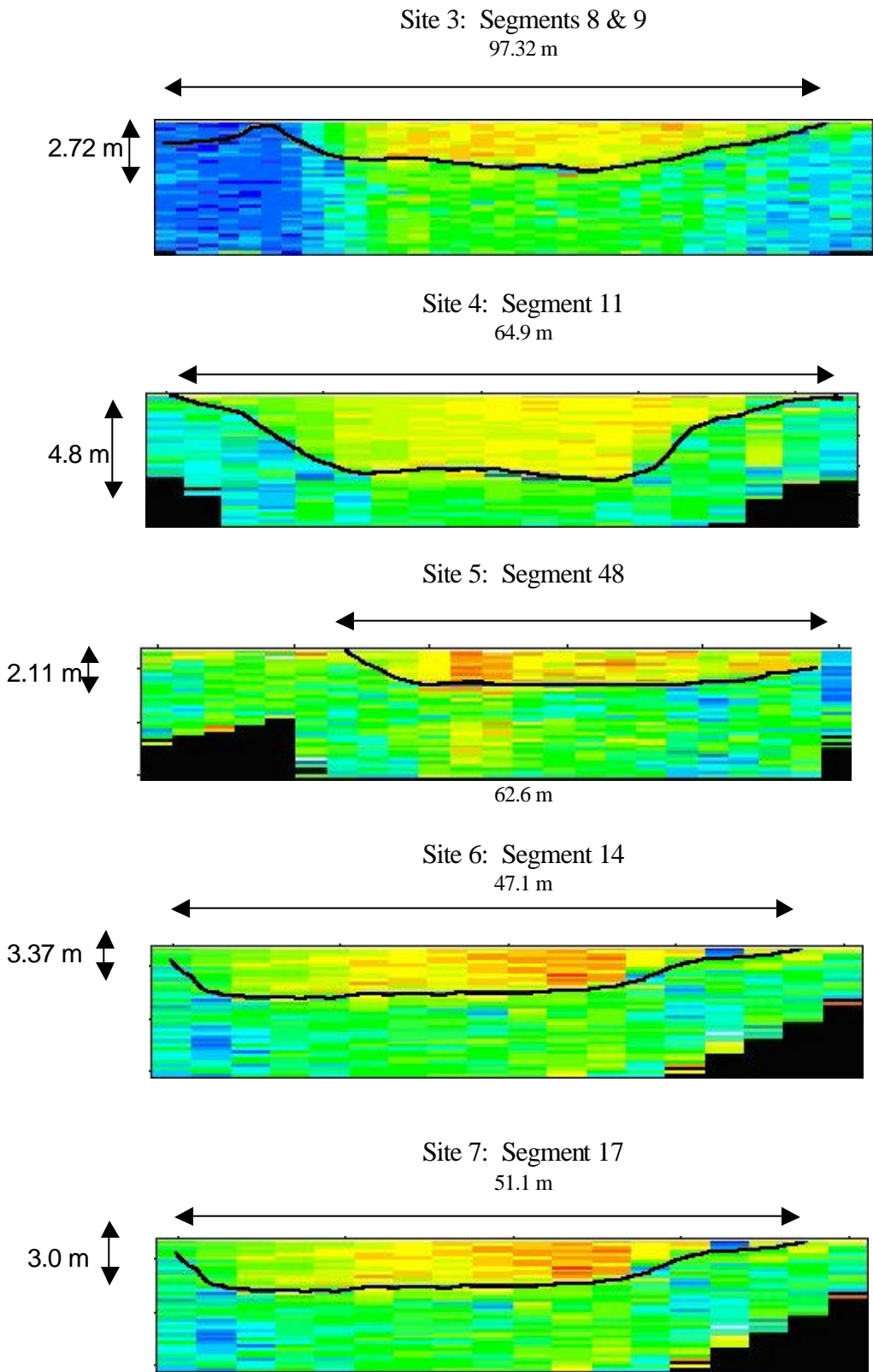


Figure 3-4 Cross Sectional Data – Sites 3-7 (ADCP Survey)

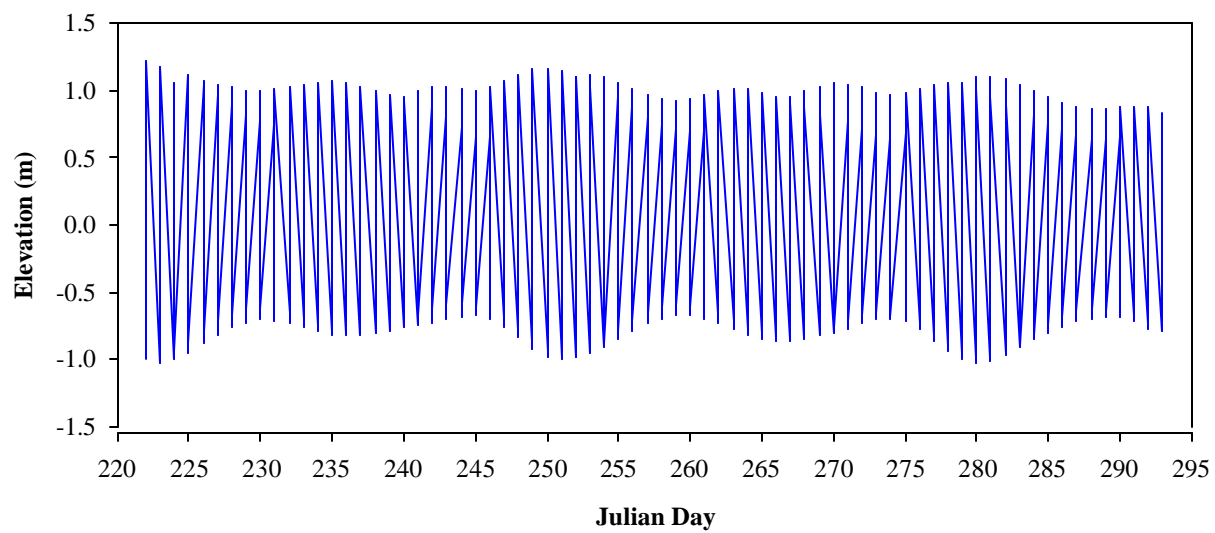
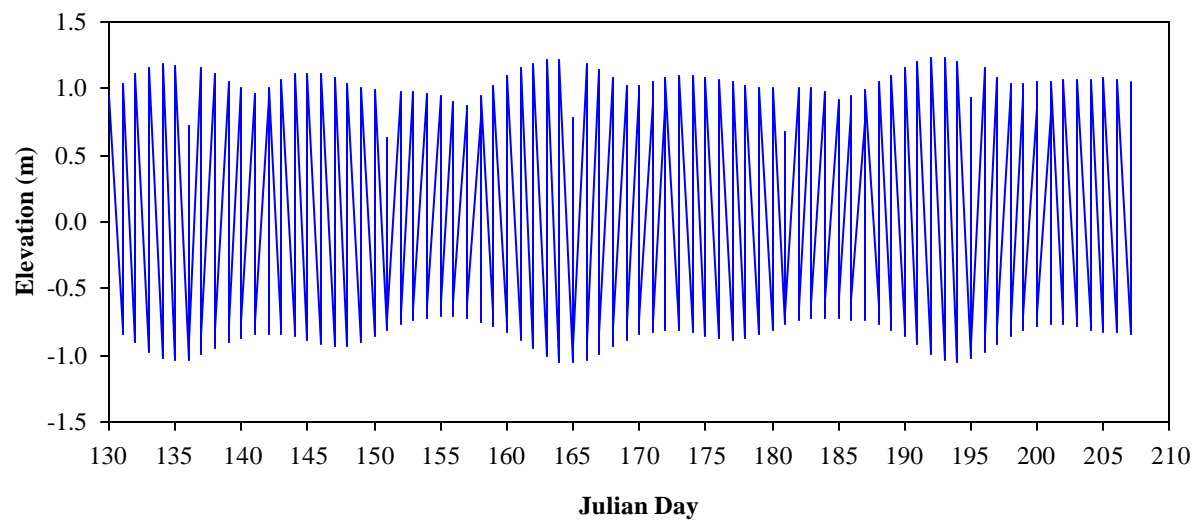


Figure 3-5 Tidal Elevation Data at the DE River Boundary (1991)

3.3. DYNHYD5 Model Framework

3.3.1 Theory

3.3.1.1. Modeling Program

The USEPA's DYNHYD5 hydrodynamic model was used to calculate water transport within the Appoquinimink River Watershed. DYNHYD5 is part of the WASP5 water quality-modeling program and solves the one-dimensional equations of continuity and momentum for a branching channel junction (link node) computational network.

The hydrodynamic model solves equations describing the propagation of a long wave through a shallow water system while conserving both momentum (energy) and volume (mass). The equation of motion, based on the conservation of momentum, predicts water velocities and flows. The equation of continuity, based on the conservation of volume, predicts water heights (heads) and volumes. This approach assumes that:

- Flow is predominantly one-dimensional,
- Coriolis and other accelerations normal to the direction of flow are negligible,
- Channels can be adequately represented by a constant top width with a variable hydraulic depth (i.e., "rectangular"),
- The wave length is significantly greater than the depth, and
- Bottom slopes are moderate.

Although no strict criteria are available for the latter two assumptions, most natural flow conditions in large rivers and estuaries would be acceptable. Dam break situations could not be simulated with DYNHYD5, nor could small mountain streams with steep slopes.

The DYNHYD model simulates the circulation patterns of water by solving two equations:

1) *The equation of motion:*

$$\frac{\partial U}{\partial t} = -U \frac{\partial U}{\partial x} + a_{g,\lambda} + a_f + a_{w,\lambda}$$

where:

$$\begin{aligned} \frac{\partial U}{\partial t} &= \text{the local inertia term, or the velocity rate of change with respect to time, [m/sec}^2\text{]} \\ U \frac{\partial U}{\partial x} &= \text{the Bernoulli acceleration, or the rate of momentum change by mass transfer; also defined as the convective inertial term from Newton's second law, [m/sec}^2\text{]} \end{aligned}$$

$a_{g,\lambda}$ = gravitational acceleration along with the λ axis of the channel, [m/sec²]

a_f = frictional acceleration, [m/sec²]

$a_{w,\lambda}$ = wind stress acceleration along axis of channel, [m/sec²]

x = distance along axis of channel, [m]

t = time, [sec]

U = velocity along the axis of channel, [m/sec²]

λ = longitudinal axis

2) *The equation of continuity:*

$$\frac{\partial A}{\partial t} = -\frac{\partial Q}{\partial x}$$

where:

A = cross sectional area, [m²]

Q = flow, [m³/sec]

For rectangular channels of constant width (B):

$$\frac{\partial H}{\partial t} = -\frac{1}{B} \frac{\partial Q}{\partial x}$$

where:

B = width, [m]

H = water surface elavation, [m]

$\frac{\partial H}{\partial t}$ = rate of water surface elevation change with respect to time, [m/sec]

$\frac{1}{B} \frac{\partial Q}{\partial x}$ = rate of water volume change with respect to distance per unit width, [m/sec]

The equations of motion and continuity form the basis of the hydrodynamic model DYNHYD5. Their solution gives velocities (U) and heads (H) throughout the water body for the duration of the simulation. Because closed-form analytical solutions are unavailable, the solution of equations requires numerical integration on a computational network, where values of U and H are calculated at discrete points in space and time. The “link-node” network solves the equations of motion and continuity at alternating grid points. At each time step, the equation of motion is solved at the links while the equation of continuity is solved at the nodes, giving

velocities for mass transport calculations and heads for pollutant concentration calculations respectively.

Picturing the links as channels conveying water and the nodes as junctions storing water allows a physical interpretation of this computational network to be envisioned. Each junction is a volumetric unit that acts as a receptacle for the water transported through its connecting channels. Taken together, the junctions account for all the water volume in the river or estuary. Parameters influencing the storage of water are defined within this junction network. Each channel is an idealized rectangular conveyor that transports water between two junctions, whose midpoints are at each end. Taken together, the channels account for all the water movement in the river or estuary. Parameters influencing the motion of water are defined within the channel network. The link-node computational network, then, can be viewed as the overlapping of two closely related physical networks of channels and junctions.

3.3.2 Model Geometry and Bathymetry

The segmentation for the expanded Appoquinimink River Watershed model (ARM1) is presented in Figure 3-6. The model is one-dimensional and consists of 51 junctions and 47 channels that average approximately one half mile in length.

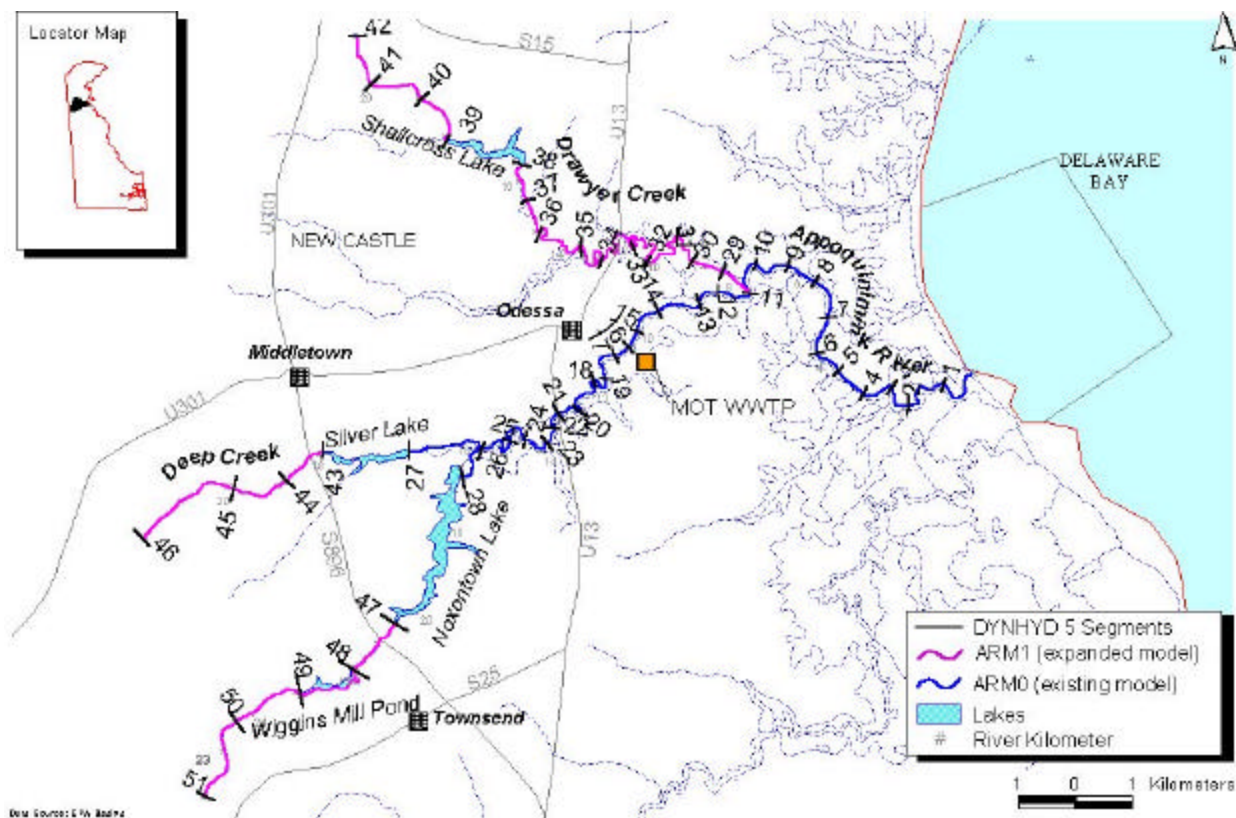


Figure 3-6 DYNHYD5 ARM1 Junctions

Four ponds were included in the expanded model grid: Noxontown Lake, Wiggins Mill Pond, Silver Lake and Shallcross Lake. Flow out of the ponds results from water flowing over the tops of the dams. With a dam forming a physical boundary to the free flow of water through the system, channel velocities are not propagated downstream of the ponds in the model framework. Only flows entering the pond are passed to the downstream model junction.

As previously mentioned, the data used to extend the hydrodynamic model of the Appoquinimink River was obtained from four data sources (1993 DYNHYD5 model, DNREC geometry, RF3 data and USGS topographic maps) and used in setting up the geometry (width, initial depth and elevation) for the DYNHYD5 model. None of the data sources alone provided the complete data set needed for the model grid. Therefore, best professional judgment was used to integrate the data sources into one picture of the river to resolve discrepancies and inconsistencies between and within the data sources, and to make estimates where data gaps existed.

Using the data as a guide, widths and depths were assigned for each model junction. Manning's 'n' which describes the bottom roughness, varied between 0.035 and 0.065. Increased roughness coefficients of 0.10 were used for three channels at the confluence of Drawyer Creek and the Appoquinimink River to improve the DYNHYD5 comparisons to the ARM0 model output. The roughness coefficients were adjusted based on the values of the coefficients of the previous modeling study (ARM0) geometry .

3.3.2.1. Model Forcing Data

Freshwater flows at the upstream boundaries and tide data at the downstream boundary were the primary forcing functions in the model. The water loss due to evaporation from the water surface and the addition of water due to precipitation falling directly on the water surface were assumed to be of second-order importance and not included in the model framework. The direct effect of wind on the water surface was also assumed to be of second-order importance. The river channel is relatively narrow and would, therefore, not be strongly impacted by winds. The effect of wind on Delaware Bay is reflected in the tidal data and, therefore, is included in the model indirectly through the tidal data used to drive the downstream boundary. A total of four boundary conditions are included in the model; the open tidal boundary at Delaware Bay and three upstream freshwater inputs (Drawyer Creek, Deep Creek and the Appoquinimink River).

3.3.2.2. Tidal Boundary

An open water boundary was located at the mouth of the river to Delaware Bay (junction 1), which is driven by the tidal conditions in the Delaware Bay.

Tidal information used in the ARM0 (1991 model setup) was used to drive the downstream model boundary. This data has been described in Section 3.2.1.3 and presented in Figure 3-5.

3.3.2.3. Fresh Water Flows

Flow enters the model through one of three possible mechanisms: upstream boundaries (Drawyer Creek, Deep Creek and upstream Appoquinimink River), tributaries, or direct runoff into a model junction. Three freshwater inputs were assigned at upstream boundary for Drawyer

Creek, Deep Creek and the Appoquinimink River (Table 3-3). These freshwater inputs are constant flows and are not affected by tidal conditions in the lower Appoquinimink River. The flows for the upstream boundaries were determined based on the ratio of the drainage area of each sub basin to the drainage area of the gagged sub basin. At each of the three upstream boundary locations, the following constant flows were assigned.

Table 3-3 Freshwater Inflows

Location	Junction	Inflows (cfs)
Drawyer Creek	42	13.5
Deep Creek	46	4.0
Appoquinimink River	51	4.0

3.3.2.4. Initial Conditions

Initial conditions were assigned to each model segment for each system being modeled based on the ARM0 initial conditions, these conditions included the initial mean velocities (m/s). An average initial velocity of 0.001 m/s was specified for all the channels.

3.4. DYNHYD5 Calibration/Validation

HydroQual was contracted to expand the existing TMDL model of the Appoquinimink River (ARM0) to upstream areas not included in the original model study area. These expanded areas include Drawyer Creek and Shallcross Lake, Deep Creek and Silver Lake, and the upstream Appoquinimink River including Wiggins Mill Pond and Noxontown Lake. This new expanded model is referred to as ARM1. Since new data was not available for this phase of the model expansion, additional calibration analyses could not be completed. In addition, since the existing TMDL for the main stem of the Appoquinimink River is based on the 1993 TetraTech model (ARM0), the expanded model (ARM1) primarily used the same base-line conditions, assumptions, and parameters to avoid any inconsistencies. Therefore, the expanded hydrodynamic model (ARM1) was calibrated to match the results of the 1993 adjusted model (ARM0). The same periods used to calibrate and validate the ARM0 model (calibration: August 10, 1991 to October 14, 1991 and validation: May 10, 1991 through July 25, 1991) were also used to calibrate and validate the ARM1 model. With additional upstream segments and new geometry data, the ARM1 model was calibrated primarily by performing adjustments to Manning's 'n' and refinements to the model geometry. This is the same approach used in the 1993 calibration efforts and included adjusting parameters to conform within the ranges used in the earlier modeling work (ARM0). Inconsistencies between the ARM0 model input channel lengths and widths, and junction surface areas were corrected in the ARM1 model with the channel lengths and widths used to calculate the new surface areas. In addition, the large boundary junction required in the original ARM0 model was not required in the ARM1 model and the correct surface area was used.

3.4.1 Calibration

The model was calibrated to the period from August 10 to October 14, 1991 with results presented for 6 segments (Figure 3-7). Roughness coefficients and river geometry were adjusted to match the 1993 modeling results.

The model output in segments 1, 5, 10, 15, 20, and 25 for the calibration period generated with the new expanded model (ARM1) show agreement with the model output previously generated with the 1993 model (ARM0). Cross-plots of ARM0 and ARM1 DYNHYD5 model output is presented in Figure 3-8 through Figure 3-10 for velocity, flow and depth at junctions 1, 5, 10, 15, 20 and 25 along with a line of perfect agreement (slope = 1). The new ARM1 DYNHYD5 model generally reproduces the ARM0 model output with slightly greater flood and ebb tide velocities and flows calculated with the ARM1 model at junctions 1, 5, 10, and 25. The ARM1/ARM0 agreement at junctions 15 and 20 for velocity and flow is very good. Calculated water depths from the ARM1 model also agree very well with the ARM0 results.

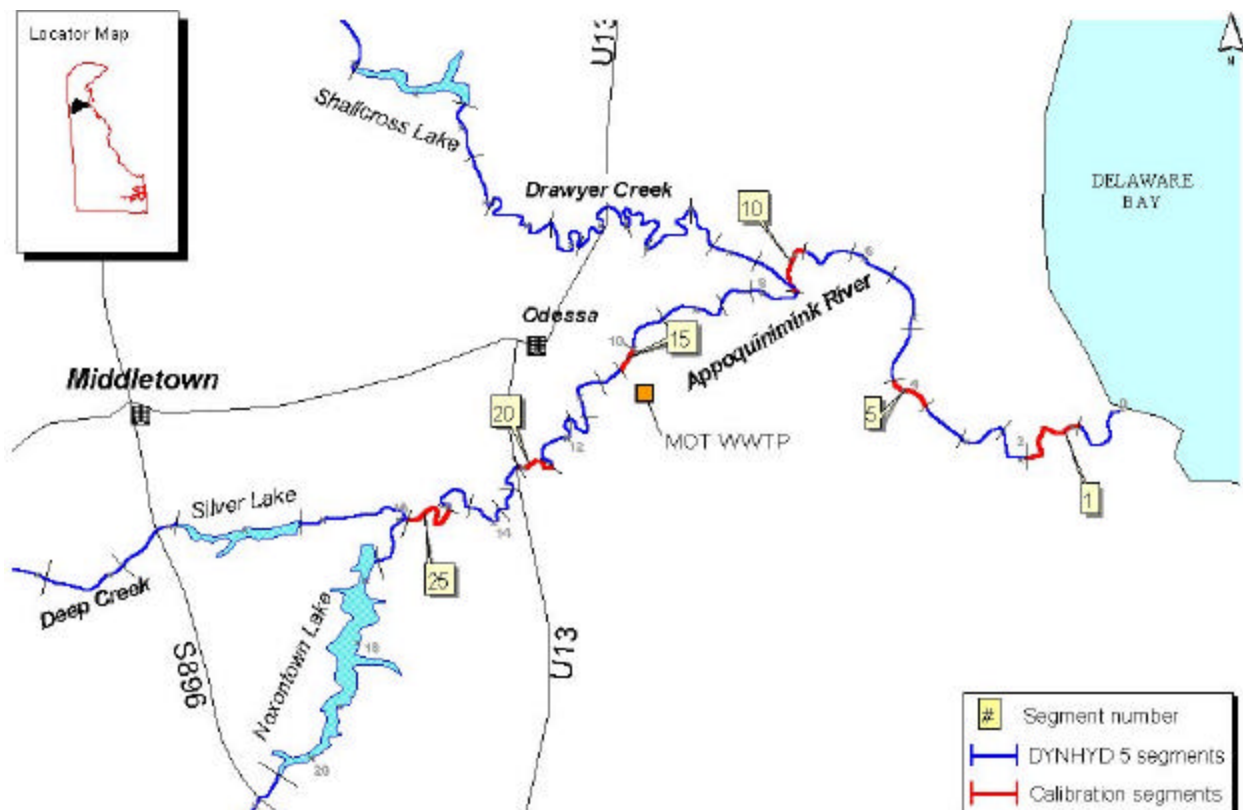


Figure 3-7 Appoquinimink River Watershed DYNHYD5 Calibration Segments

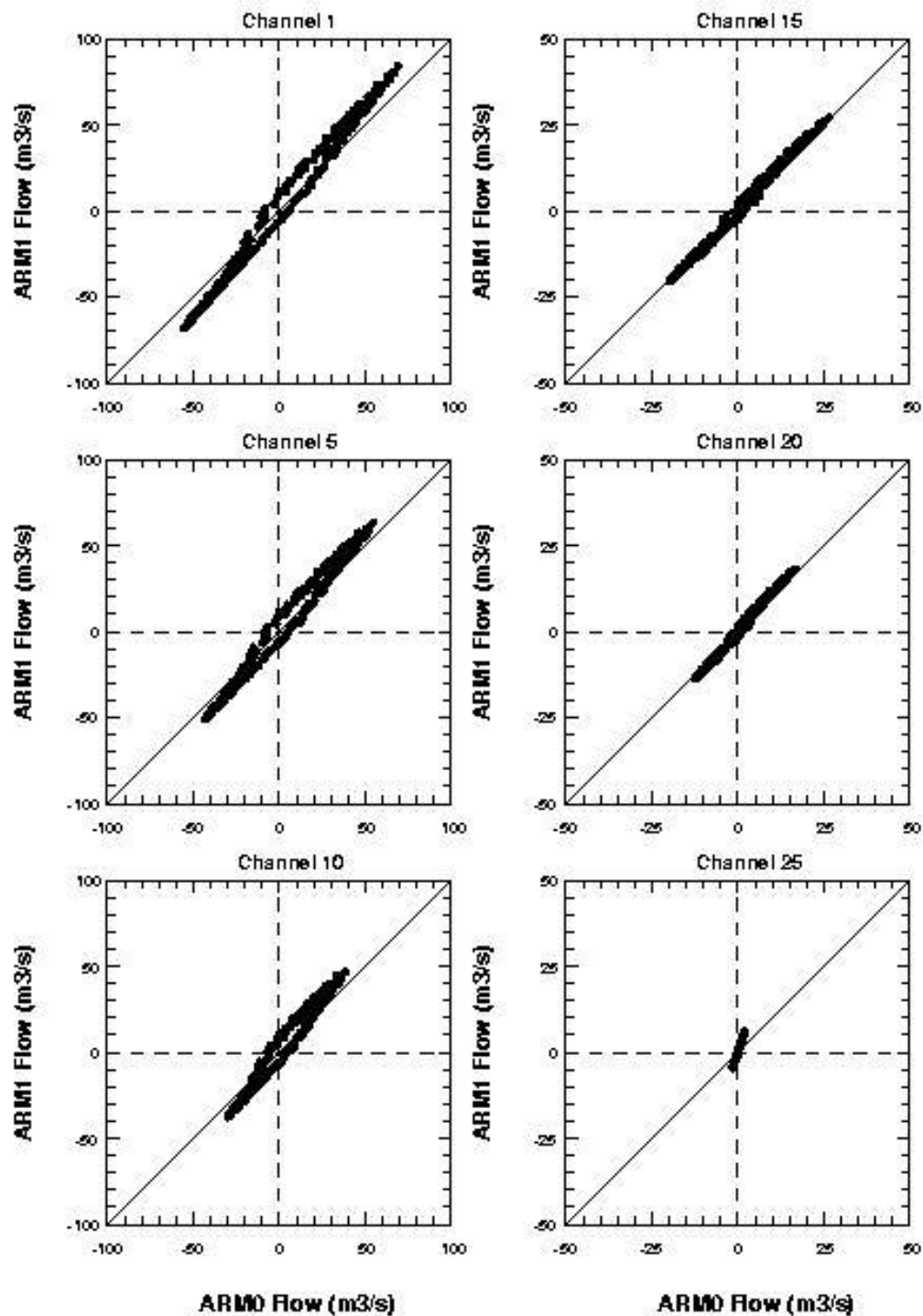


Figure 3-8 Appoquinimink River Model DYNHYD5 Calibration Flow Comparisons

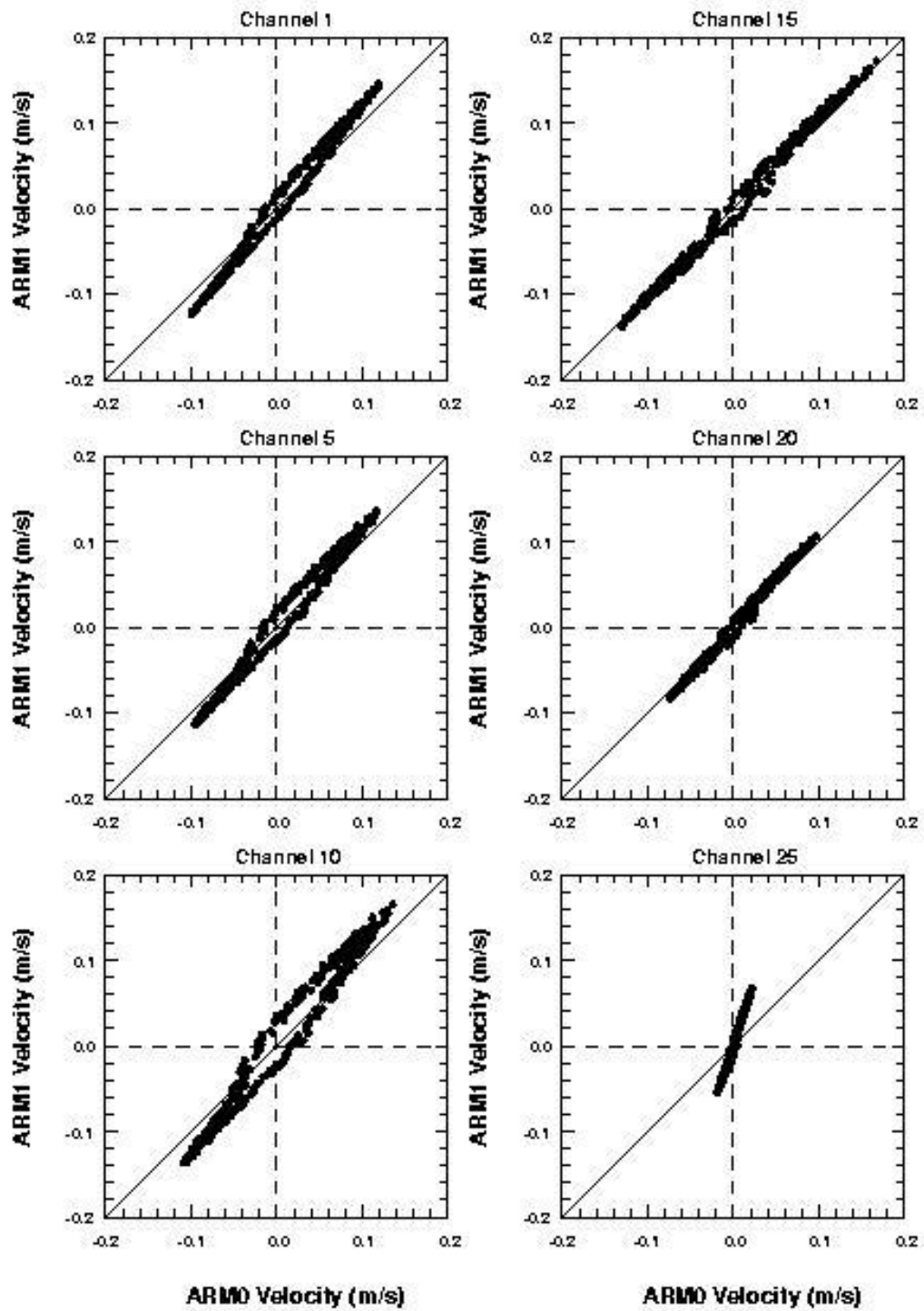


Figure 3-9 Appoquinimink River Model DYNHYD5 Calibration Velocity Comparisons

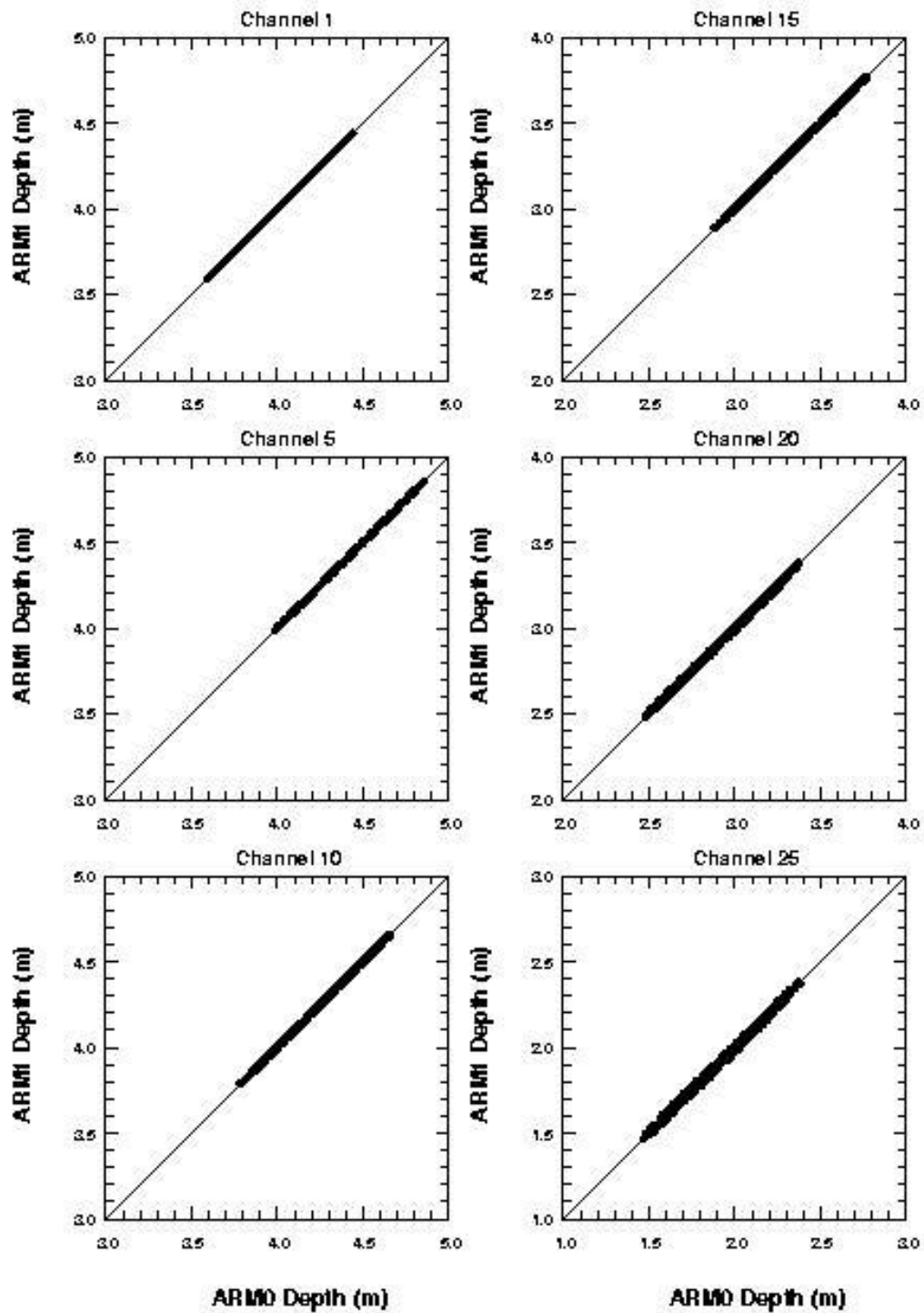


Figure 3-10 Appoquinimink River Model DYNHYD5 Calibration Depth Comparisons

3.4.2 Validation

Following calibration, the model was validated to the period between May 10 and July 25, 1991. As with the calibration period, flows, velocities and depths calculated by the ARM1 model over the validation period show agreement between the ARM1 and ARM0 models. Again the cross-plots of ARM0 and ARM1 DYNHYD5 model results are presented in Figure 3-11 through Figure 3-13 for velocity, flow and depth. The comparisons between the ARM1 and ARM0 model result in similar conclusions for the validation period as for the calibration period.

3.4.3 Tidally Averaged Transport

The tidally averaged transport from the ARM1 model during the calibration and validation period are presented in Figure 3-14 and Figure 3-15. In these figures the solid line represents the Appoquinimink River main stem, the dashed line represents Drawyer Creek and the dotted line represents Deep Creek. The tidally averaged flows ranged from 4 to 25 cfs with Drawyer Creek flow of approximately 14 cfs. Velocities ranged from approximately 5 to 45 cm/s with depths ranging from approximately 1 to 16 feet.

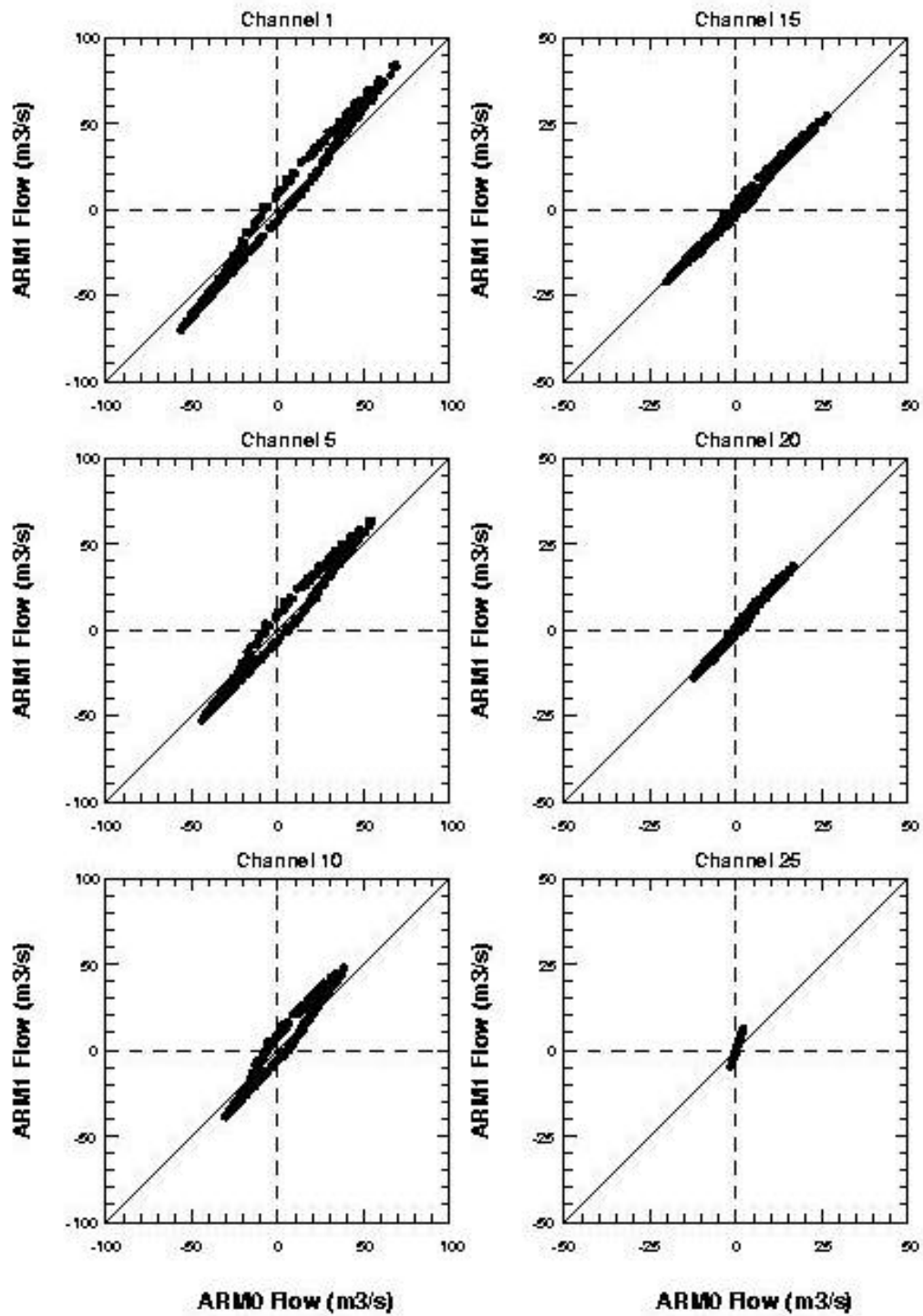


Figure 3-11 Appoquinimink River Model DYNHYD5 Verification Flow Comparisons

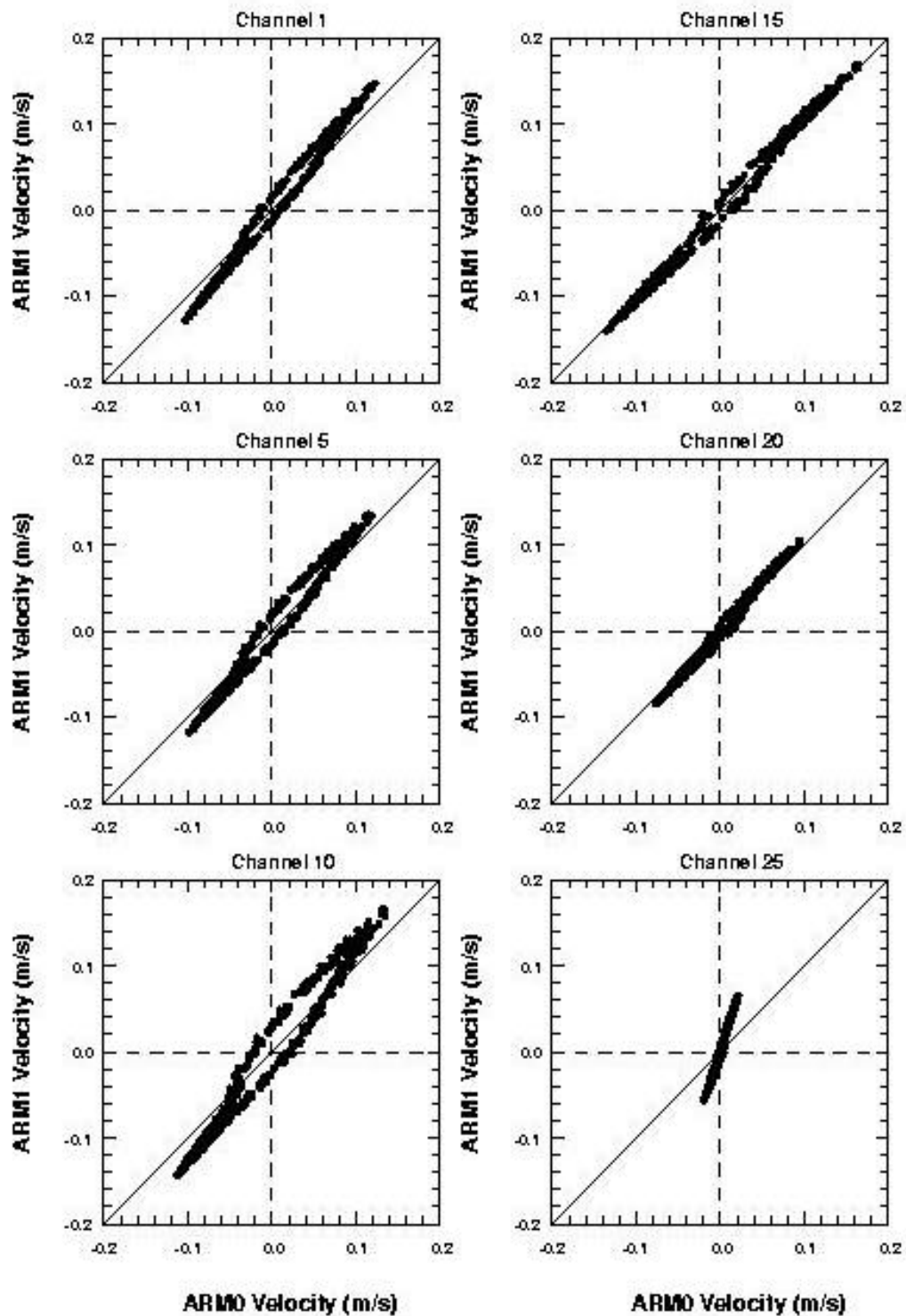


Figure 3-12 Appoquinimink River Model DYNHYD5 Verification Velocity Comparisons

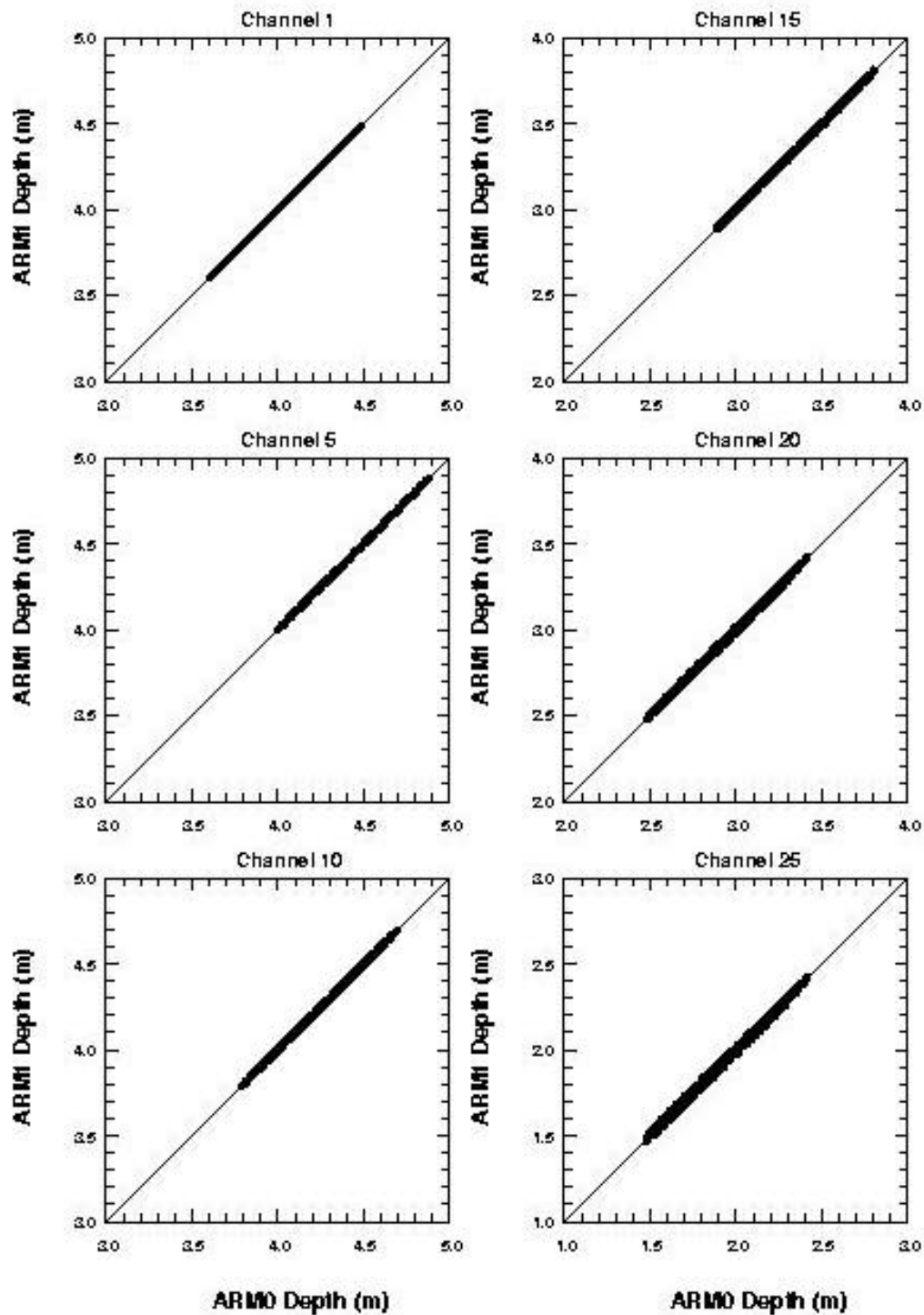


Figure 3-13 Appoquinimink River Model DYNHYD5 Verification Depth Comparisons

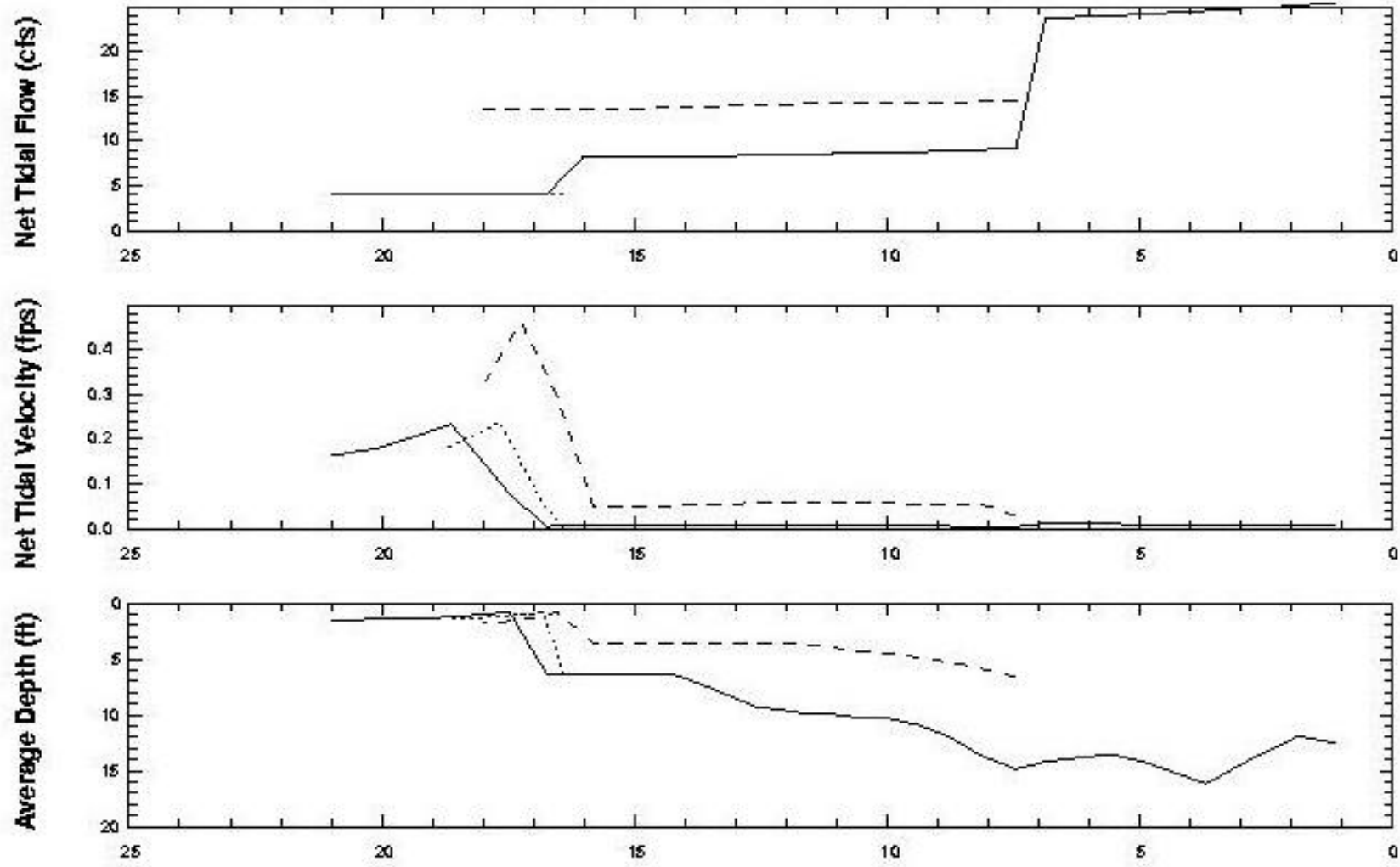


Figure 3-14 Appoquinimink River Model DYNHYD5 Model Calibration Output (ARM1)

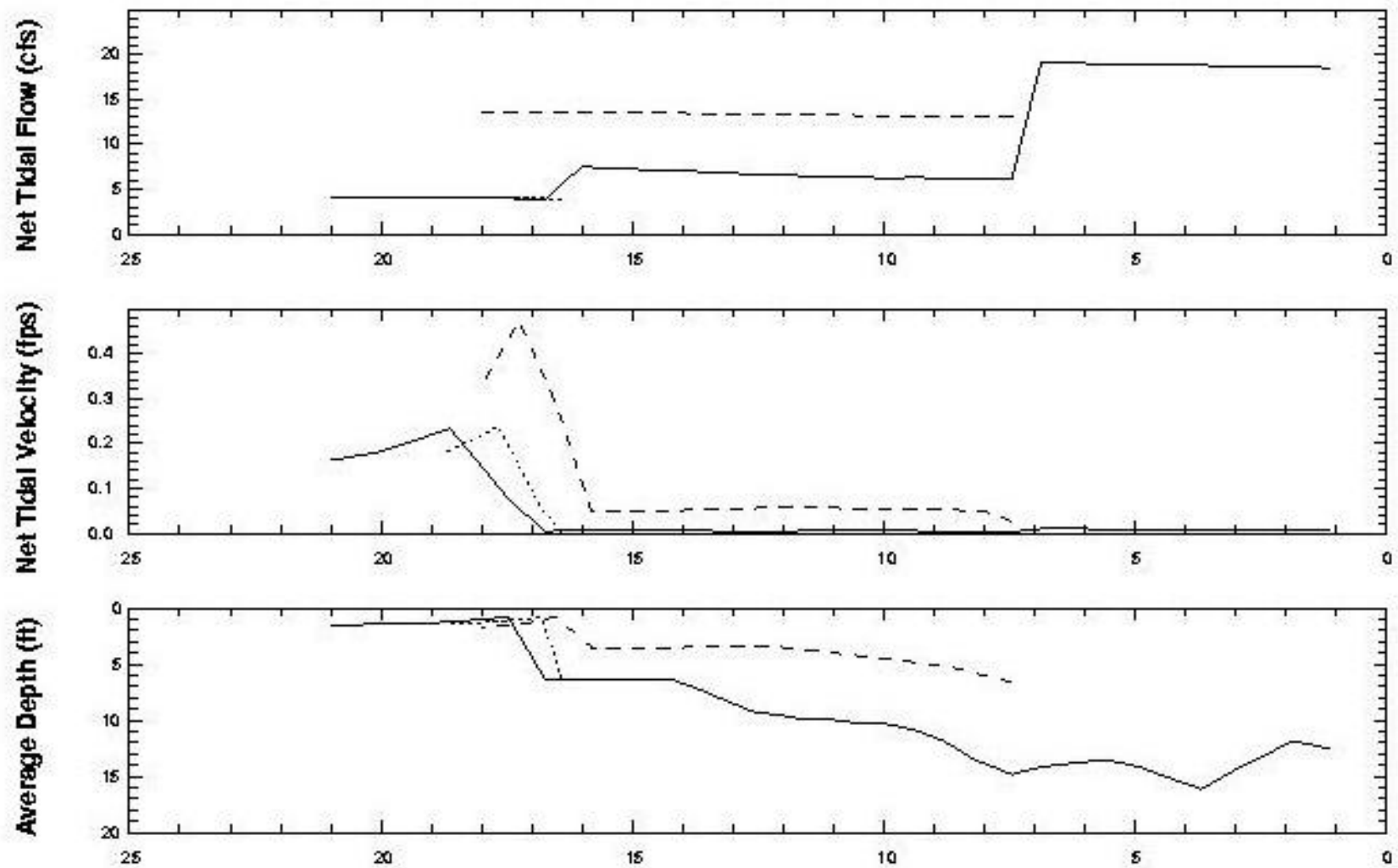


Figure 3-15 Appoquinimink River Model DYNHYD5 Model Validation Output (ARM1)

3.5. WASP5 Model Framework

3.5.1 Water Quality Modeling Framework (WASP-Eutro)

3.5.1.1. Background

The Water Quality Analysis Simulation Program5 (WASP5) is an enhancement of the original WASP (DiToro et al., 1983; Connolly and Winfield, 1984; Ambrose, R.B. et al., 1988). This model allows users to interpret and predict water quality responses to natural phenomena and man-made pollution. WASP5 is a dynamic compartmental modeling program for aquatic systems, including both the water column and the underlying benthos. The time-varying processes of advection, dispersion, point and diffuse mass loading, and boundary exchange are represented in this program.

The WASP5 system consists of two standalone computer programs, DYNHYD5 and WASP5 that can be run in conjunction or separately. The hydrodynamic program, DYNHYD5, simulates the movement of water while the water quality program, WASP5, simulates the movement and interaction of pollutants within the water. For more information regarding DYNHYD5, please refer to Section 5.1.

WASP5 is a dynamic compartmental model that can be used to analyze a variety of water quality problems in such diverse water bodies as lakes, reservoirs, rivers, estuaries, and coastal waters. WASP5 is supplied with two kinetic sub-models to simulate two of the major classes of water quality problems: conventional pollutants (involving dissolved oxygen, biochemical oxygen demand (BOD), nutrients and eutrophication) and toxic pollutants (involving organic chemicals, metals, and sediment). The linkage of either sub-model with the WASP5 program results in the models EUTRO5 and TOXI5, respectively. The water quality model for the Appoquinimink River Watershed (ARM1) uses the EUTRO5 sub-model.

The equations solved by WASP5 are based on the principle of mass conservation. This principle requires that the mass of each water quality constituent being investigated must be accounted for. WASP5 traces each water quality constituent from the point of spatial and temporal input to its final point of export, conserving mass in space and time. To perform these mass balance computations, the user must supply WASP5 with input data defining seven important characteristics:

- Simulation and output control;
- Model segmentation;
- Advective and dispersive transport;
- Boundary conditions;
- Point and diffuse source waste loads;
- Kinetic parameters, constants, and time functions; and
- Initial conditions.

These input data, together with the general WASP5 mass balance equations and the specific chemical kinetics equations, uniquely define a special set of water quality equations. These are numerically integrated by WASP5 as the simulation proceeds in time. At user specified print intervals, WASP5 saves the values of all display variables for subsequent retrieval by the postprocessor program.

3.5.1.2. Theory and Equations

The water quality modeling framework used in this study and detailed in this report is based upon the principle of conservation of mass. The conservation of mass accounts for all of a material entering or leaving a body of water, transport of the material within the water body, and physical, chemical and biological transformations of the material. For an infinitesimal volume oriented along the axis of a three-dimensional coordinate system, a mathematical formulation for the conservation of mass may be written:

$$\frac{\partial c}{\partial t} = \underbrace{\frac{\partial}{\partial x} \left(E_x \frac{\partial c}{\partial x} \right) + \frac{\partial}{\partial y} \left(E_y \frac{\partial c}{\partial y} \right) + \frac{\partial}{\partial z} \left(E_z \frac{\partial c}{\partial z} \right)}_{\text{dispersive transport}} - \underbrace{U_x \frac{\partial c}{\partial x} - U_y \frac{\partial c}{\partial y} - U_z \frac{\partial c}{\partial z}}_{\text{advective transport}} \quad (7-1)$$

where:

c = concentration of water quality variable [M/L^3];

t = time [T];

E = dispersion (mixing) coefficient due to tides and density and velocity gradients [L^2/T];

U = advective velocity [L/T];

S_L = external inputs of the variable c [M/L^3-T];

S_B = boundary loading rate (including upstream, downstream, benthic and atmospheric inputs) [M/L^3-T];

S_K = sources and sinks of the water quality variable, representing kinetic interactions [M/L^3-T];

x, y, z = longitudinal, lateral and vertical coordinates; and

M, L, T = units of mass, length and time, respectively.

The model framework used in this study is comprised of three components:

- 1) Transport due to advective freshwater flow and density-driven tidal currents and dispersion;
- 2) Kinetics which control the physical, chemical and biological reactions being modeled (sources and sinks); and
- 3) External inputs entering the system (point sources, non-point sources and boundary conditions).

The transport within the Appoquinimink River Watershed System is a complex process affected by freshwater inflows, temperature, wind, and offshore forcing from the coastal shelf via the Delaware Bay. This transport was determined by the hydrodynamic model previously presented in Section 6. The hourly average fluxes from this hydrodynamic model were used to drive the transport field of the water quality model.

The kinetics represent the rates of reaction among water quality variables and approximate the physical, chemical and biological processes occurring in the Appoquinimink River Watershed. The kinetic framework of the water quality model is presented in Figure 3-16.

External inputs of carbonaceous biochemical oxygen demand (CBOD), nutrients (nitrogen and phosphorus) and other model variables are from point sources, non-point sources and model boundary conditions.

The modeling framework used in this study utilized the following state-variables:

- 1 - Ammonia Nitrogen (NH_3);
- 2 - Nitrate (NO_3);
- 3 - Dissolved Inorganic Phosphorus (PO_4);
- 4 - Phytoplankton (PHYT);
- 5 - Carbonaceous Biochemical Oxygen Demand (CBOD);
- 6 - Dissolved Oxygen (DO);
- 7 - Organic Nitrogen (Org N); and
- 8 - Particulate Organic Phosphorus (Org P).

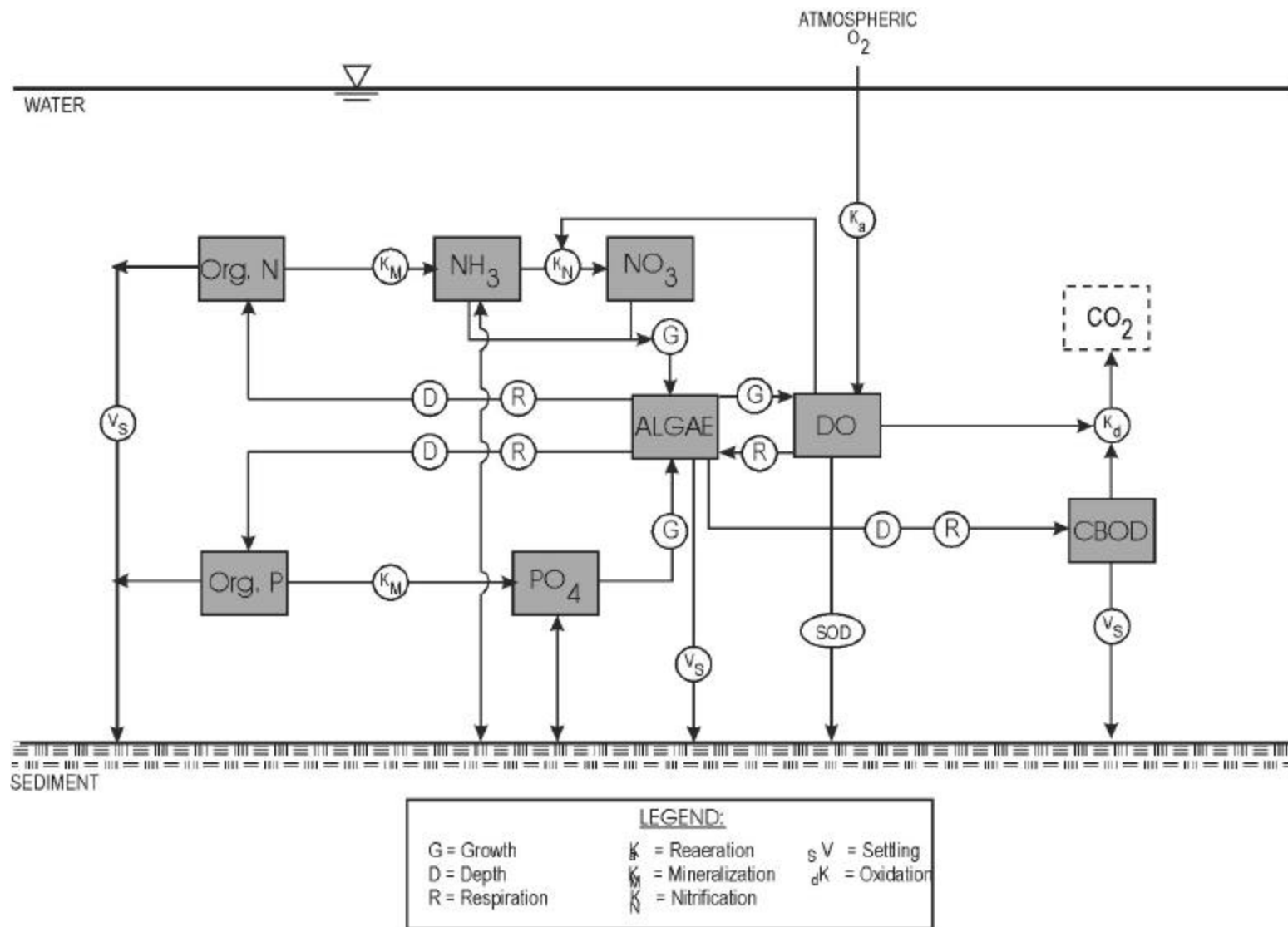


Figure 3-16 WASP-EUTRO5 Water Quality Model Kinetic Framework for the Appoquinimink River Watershed

3.5.2 Model Grid

The model segmentation for the Appoquinimink River Watershed water quality model is presented in Figure 7-2. The model is one-dimensional and consists of 47 water quality segments that average approximately one mile in length with one sediment segment for the entire model domain. The model segmentation is based on the DYNHYD5 model of the Appoquinimink River Watershed with the junctions used for water quality model segments. The original ARM0 water quality model improperly assigned the boundary condition segments in the model setup. It is necessary to assign the water quality boundary conditions one segment in from the DYNHYD5 boundary condition junctions. The proper assignment of water quality boundary condition segments was completed in the ARM1 WASP5 model. This improper assignment of boundary condition segments in the ARM0 model was noticed in the ARM1 model when the assigned boundary conditions were not properly affecting the internal model calculations.

3.6. WASP5 Model Calibration/Validation

The expanded WASP5 model (ARM1) calibration and validation results are compared to the results of the previous model (ARM0) and the data collected during the calibration period (August 11, 1991 to October 19, 1991) and validation period (May 10, 1991 to July 25, 1991). The model calibration and validation results for each parameter are presented in the following sections which show the data collected during each modeling period, the period average and range in model values calculated over that modeling period.

During this process it was noted that the WASP5 volumes used in the original ARM0 model did not correlate with the assigned lengths, widths and depths in the DYNHYD5 model. In order to be consistent between the DYNHYD5 and WASP5 models, re-calculated volumes were assigned in the new ARM1 WASP5 model based on the new DYNHYD5 model lengths, widths and depths.

3.6.1 Forcing Functions

Initial Conditions

Prior to the start of a model simulation, an initial condition was assigned to each segment for each of the eight systems (ON, NH₃, NO_x, OP, PO₄, CBOD, DO, chl-a) being modeled. The initial conditions used for both modeling periods for the new model segments were based on the ARM0 model and expanded to the upstream reaches for Silver Lake, Noxontown Lake and Drawyer Creek.

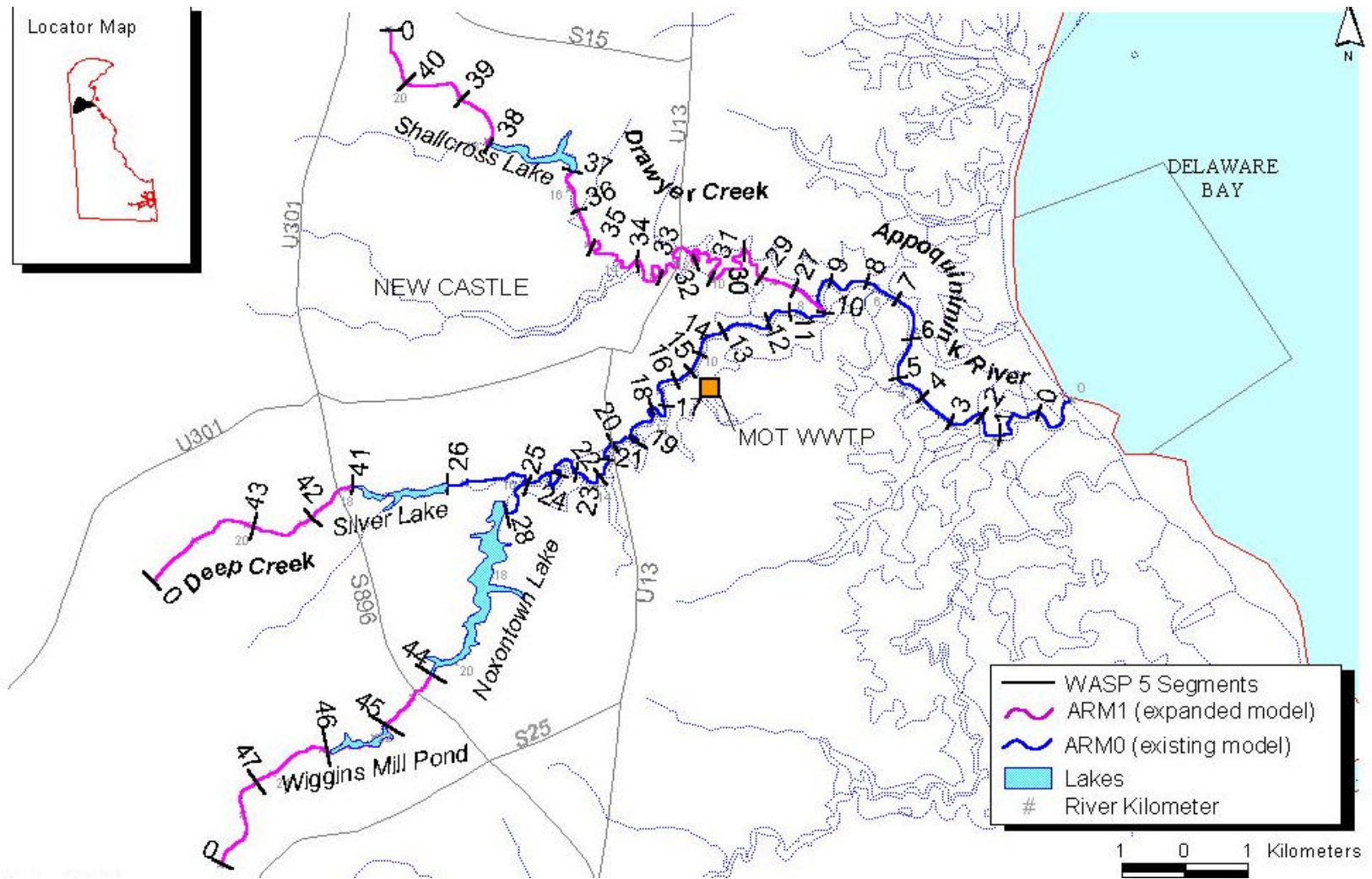


Figure 3-17 WASP5 ARM1 Segments, Appoquinimink River Watershed

Boundary Conditions

A total of four boundary conditions were accounted for in the model, including an open water boundary located at the Delaware Bay (segment 1) which is driven by the tidal conditions in the Bay. The three other boundaries are upstream freshwater inputs for Drawyer Creek (segment 40), Deep Creek (segment 43) and main stem Appoquinimink River (segment 47). The freshwater inputs are constant flows and are not affected by tidal conditions in the lower Appoquinimink River.

No data was available on the modeled periods for the new model segments. At the upstream boundary locations, the boundary conditions used in the ARM0 model were used for the boundary concentrations in the ARM1 model.

3.6.2 Pollutant Loading

Point Source Loads

One municipal point source is located in the Appoquinimink River Watershed, the Middletown-Odessa-Townsend WWTP, which discharges approximately 0.5 MGD. This point source, was previously included in the ARM0 model and the daily loading values used are listed in Table 3-4.

Table 3-4 Point Source Loads

Parameter	Load (kg/d)
NH ₃	18.9
NO ₃ +NO ₂	0
PO ₄	1.6
Chl-a	0
CBOD ₅	36.9
DO	1.3
ON	9.5
OP	4.8

Only daily average data was available to assign loads for the New Castle County WWTP and by using constant values, uncertainty in the actual daily load is incorporated into the model calculation.

3.6.3 Calibration Period

The model-data comparisons for the calibration period are presented in Figure 3-18. The data are shown as the filled symbols (average and range) and the average main stem Appoquinimink River model results during the calibration period are presented as a solid line with the shaded region representing the range calculated during the period. The data for the Drawyer Creek period average model output is presented as the dashed line while the dotted line represents the Deep Creek model output. Model (ARM1) and data comparisons are presented for organic nitrogen (Org N), ammonia nitrogen (NH₃), nitrite plus nitrate nitrogen (NO₂+NO₃), organic phosphorus (Org P), orthophosphate (PO₄), carbonaceous BOD (CBOD), dissolved

oxygen (DO) and chlorophyll “a”. Overall the model reasonably reproduces the available field data in the Appoquinimink River main stem for all parameters. No data was available for Drawyer Creek and Deep Creek during the modeled time period making it impossible to compare the model results to the observed data.

Due to the improper boundary condition assignment and WASP5 volume inconsistencies between the DYNHYD5 model lengths, width and depths in the original ARM0 model, more weight was placed on reproducing the observed water quality data rather than the original ARM0 model output. An example of the ARM1 versus ARM0 model outputs is presented in Figure 3-19. The ARM0 model results are shown in blue and the ARM1 model results in red. Reasonable agreement between the ARM1 and ARM0 model outputs is obtained.

3.6.4 Validation Period

The results of the model validation are presented in Figure 3-20 and Figure 3-21 in the same format as the calibration figures. Again, the ARM1 model reasonably reproduces the observed data for the Appoquinimink River main stem. Data were not available for comparison in the expanded areas of the model.

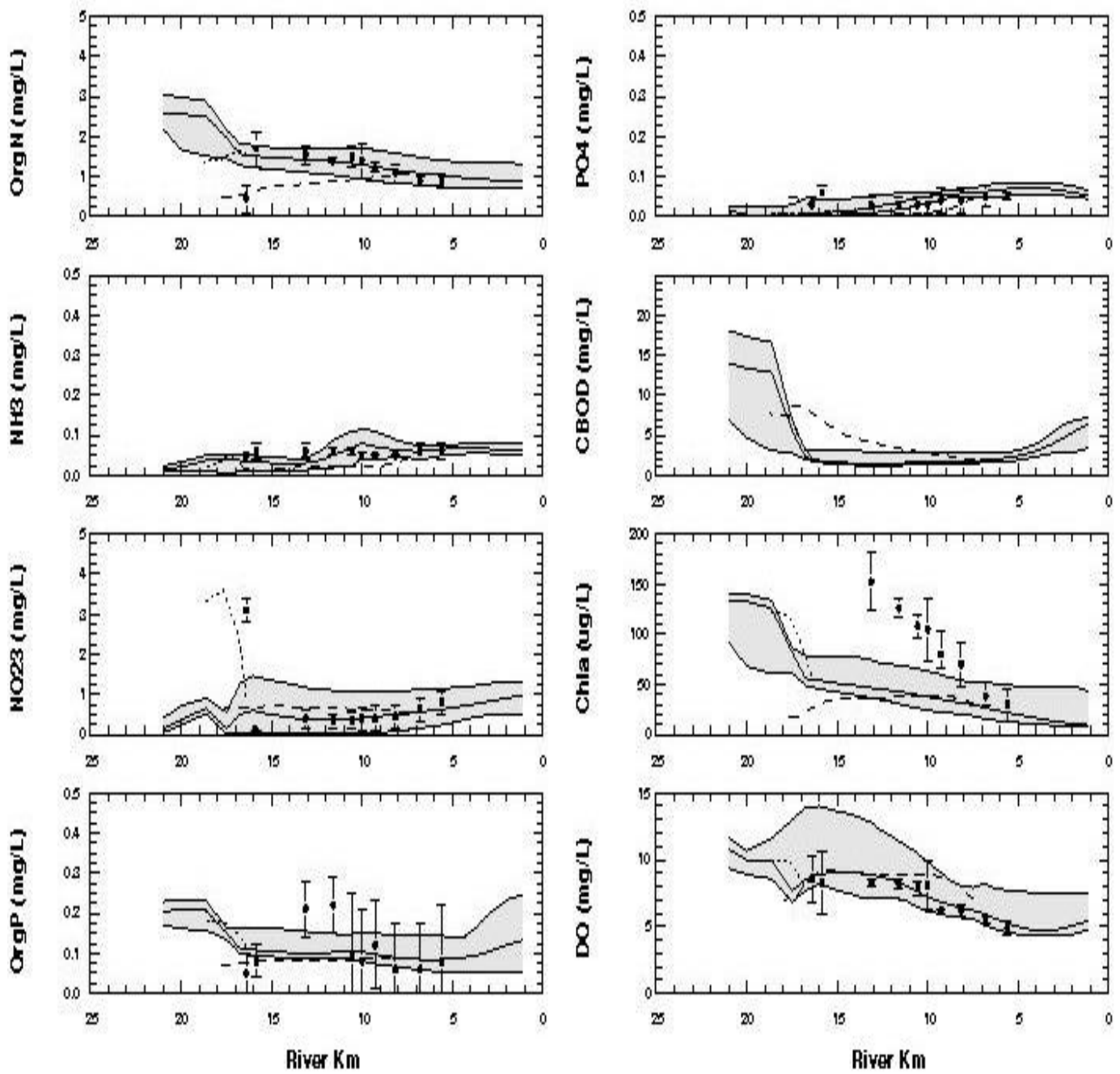


Figure 3-18 Appoquinimink River Model Calibration Output (ARM1)

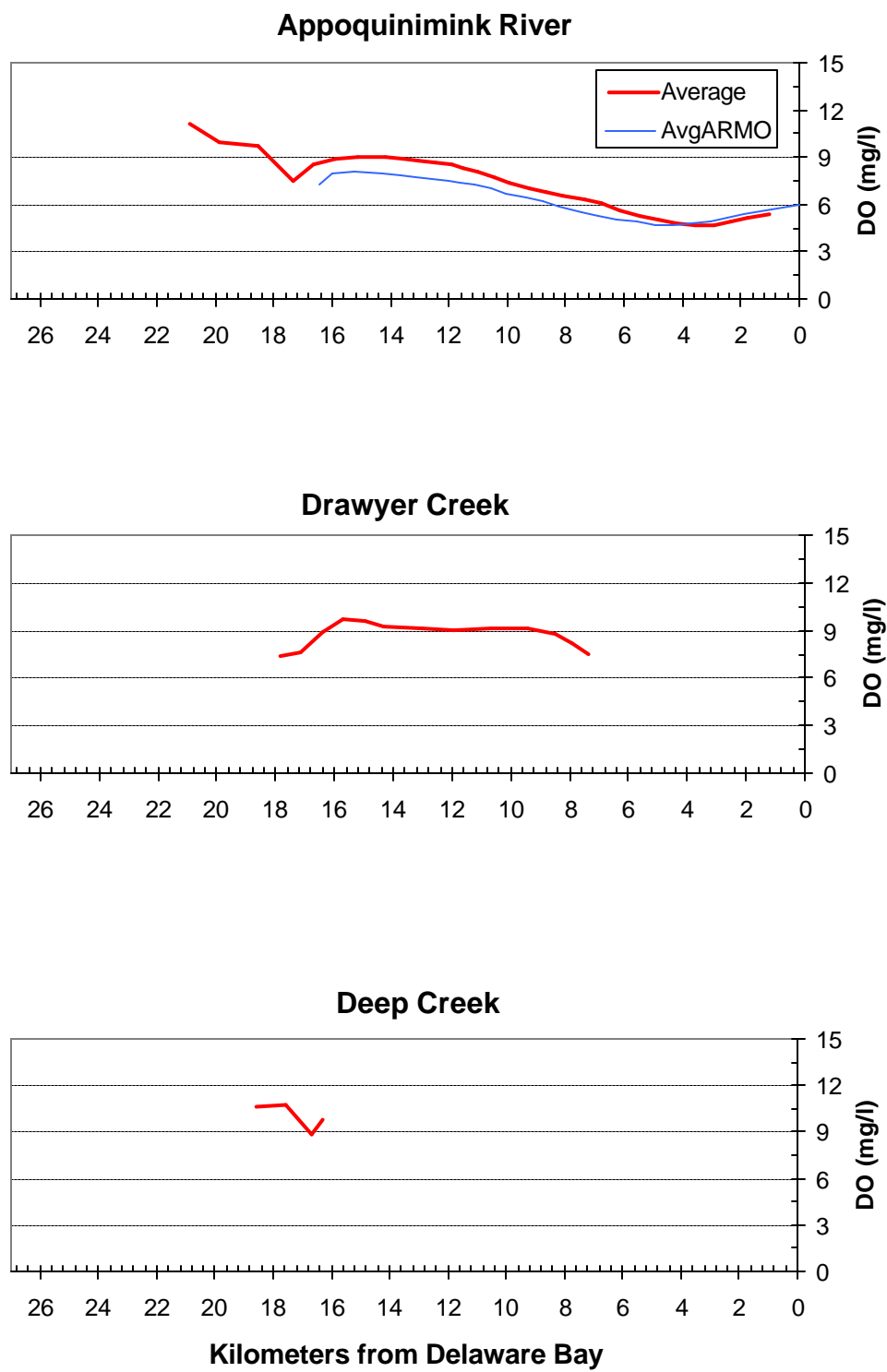


Figure 3-19 Average DO ARM0 Versus ARM1, Calibration Period

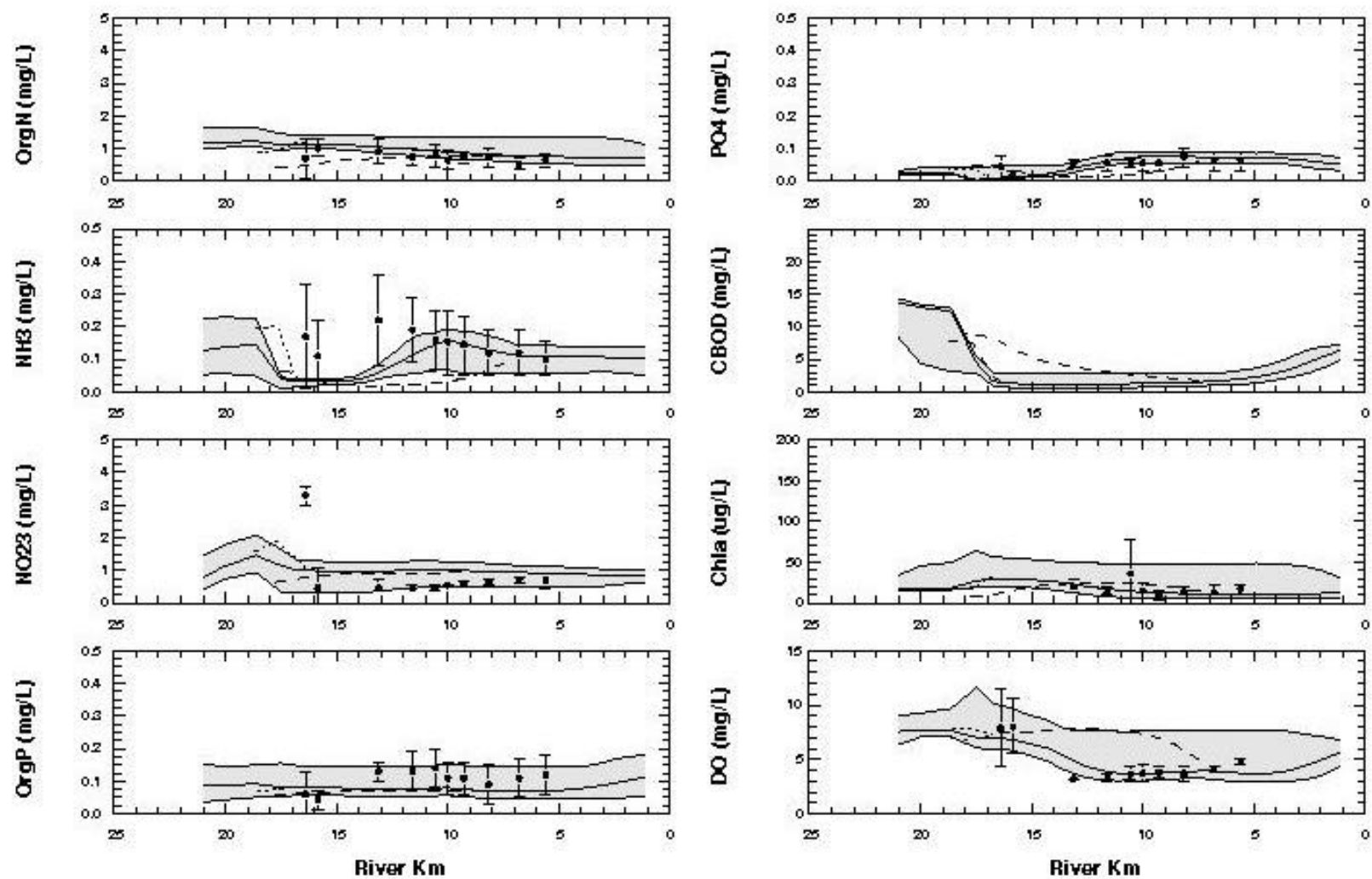


Figure 3-20 Appoquinimink River Model Verification Output (ARM1)

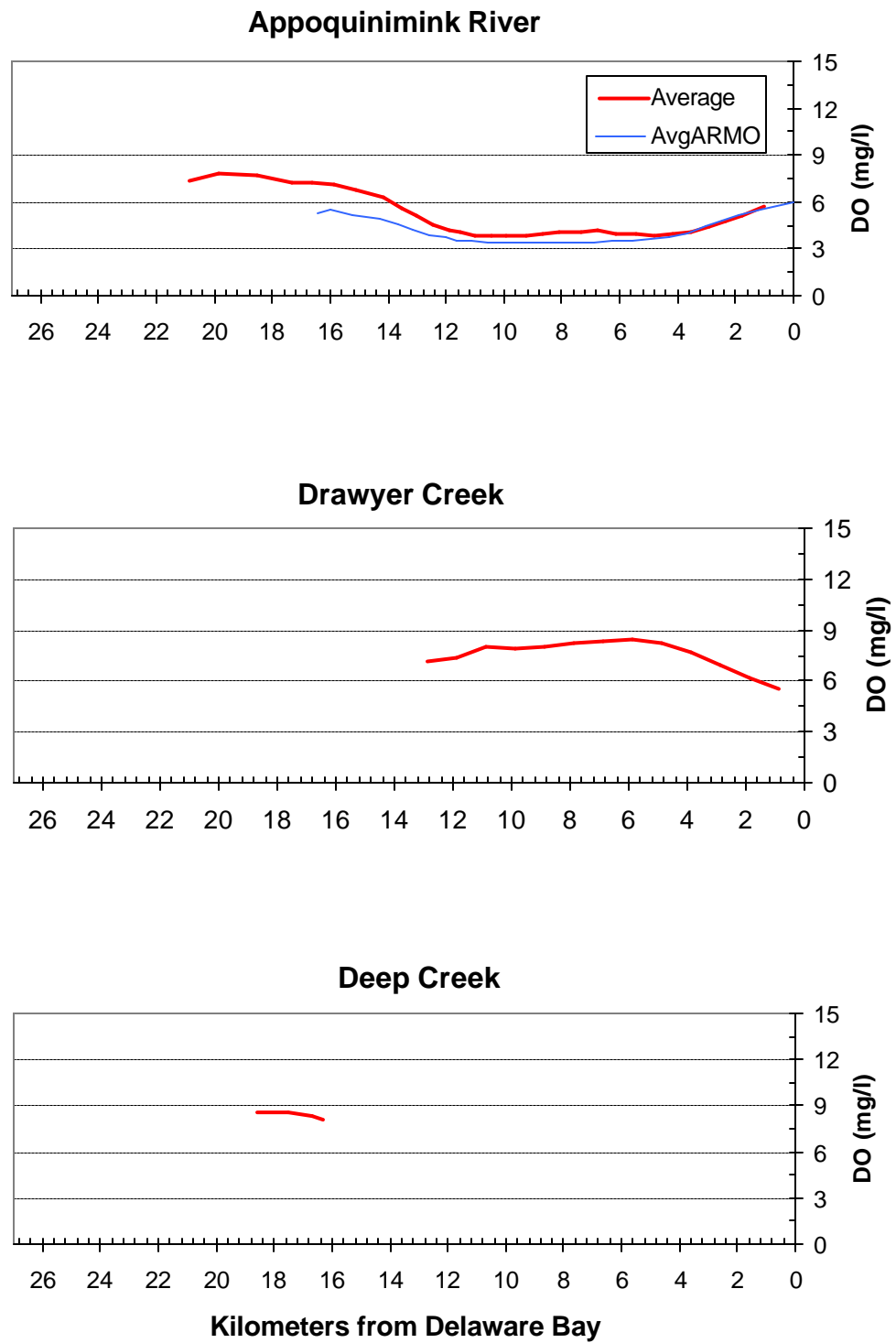


Figure 3-21 Average DO ARM0 Versus ARM1, Verification Period

4. Adjusting ARM1 to Reflect Current Conditions

Recent water quality data was compiled at a number of stations in the Appoquinimink River watershed. This data comes from 17 DNREC monitoring stations (Figure 4-1) as presented below.

- 109091 – Mouth of Appoquinimink River to Delaware Bay;
- 109121 – Appoquinimink River at Route 9 Bridge;
- 109141 – Appoquinimink River at mouth of East Branch Drawyer Creek;
- 109151 – Appoquinimink River above West Branch Drawyer Creek;
- 109051 – Appoquinimink River at Route 299 Bridge (Odessa);
- 109171 – Appoquinimink River west bank from MOT WWTP;
- 109041 – Appoquinimink River at Route 13 Bridge;
- 109131 – Noxontown Pond Overflow (Road 38);
- 109221 – Downstream from Wiggins Mill Pond at Route 71;
- 109231 – Upstream from Wiggins Mill Pond at Grears Corner Road;
- 109071 – Drawyer Creek at Route 13;
- 109191 – Shallcross Lake Overflow;
- 109211 – Drawyer Creek above Shallcross Lake at Cedar Lane Road;
- 109201 – Tributary to Drawyer Creek at Marl Pit Road;
- 109031 – Silver Lake Overflow;
- 109241 – Deep Creek at DE Route 15;
- 109251 – Deep Creek above Silver Lake at Route 71;

This recent data set was used to assess the model results in Drawyer Creek, Deep Creek and the upstream Appoquinimink River areas that were added into the ARM1 model (1991 data). In general, the recent Drawyer Creek data (Stations 109071, 109191 and 109211) for nutrients, chlorophyll-a, BOD and DO is reasonably represented by the ARM1 model. Differences can be due to a number of factors such as river flow, tidal forcing, NPS loads, meteorology, change in land use, pollution control strategies, etc.. The same conclusions can be drawn for Deep Creek (Stations 109031, 109241 and 109251) and the upstream Appoquinimink River (Stations 109131, 109221 and 109231) areas. Figure 4-2 illustrates the average values for the total N, total P, DO, and CBOD₅ values for the time period prior to 1997 versus the values obtained between 1997 through 2000. The red symbols indicate the concentrations at each station prior to 1997 and the blue symbols reflect the 1997 through 2000 concentrations. It is clear that the average total N concentrations have decreased while the average total P concentrations have increased between these two time periods. With the exception of one station, the average N values all fall below the 3.0 mg/L concentration (maximum target criteria). In contrast, over half of the stations report average total P values higher than 0.2 mg/L (maximum target criteria). The DO and CBOD₅ levels are relatively consistent. Figure 4-3 illustrates the '97-'00 data with the inclusion of the minimum and maximum values at each station. In addition, the symbols are color coded to indicate which segment they are located on: blue for the Appoquinimink River, pink for Deep Creek, green for Drawyer Creek and red for station 109201 located on a tributary

off of Drawyer Creek. Although the minimum daily average standard for DO (5.5 mg/L) is met, the minimum (4 mg/L) is not. The daily averages for nutrients fall within the targets (1-3 mg N/L, 0.1-0.2mg P/L) but there are maximum values over 400% greater than those ranges. The highest concentrations of total P are in Drawyer Creek while the highest total N concentrations are found in Deep Creek. The lowest levels of DO are in the Appoquinimink River.

To better reflect the current conditions this data was incorporated into the ARM1 model. Prior to the integration of this new data, a sensitivity analysis was performed to evaluate the effect of changing the variables and parameters defined within the model. Table 4-1 reflects the effect of changing model parameters on the total N, total P, CBOD, Chl-a, and DO. The concentration changes listed reflect the average concentration change within all the waters modeled in the watershed. By evaluating the responses to changes in the parameters, e.g. increasing SOD causes DO to decline, it was determined that the inclusion of the 1997-2000 data would not harm the integrity of the ARM1 model while providing a better picture of the current conditions and a more meaningful baseline to simulate load reductions scenarios. Detailed graphs displaying each scenario are included in Appendix A.

Station 109201 (Marl Pit Rd.) data reflected a high P concentration that was not included in the ARM0 model. Because of its high P levels and drainage from the Middletown area in which significant development is occurring, the boundary condition flow and nutrient load for the Drawyer was adjusted to incorporate this tributary. A constant flow input (0.080 m³/s) at section 34 was added and the flow at section 42 was reduced from 0.381 m³/s to 0.301 m³/s. The corresponding nutrient load was added into the NPS auxiliary input file.

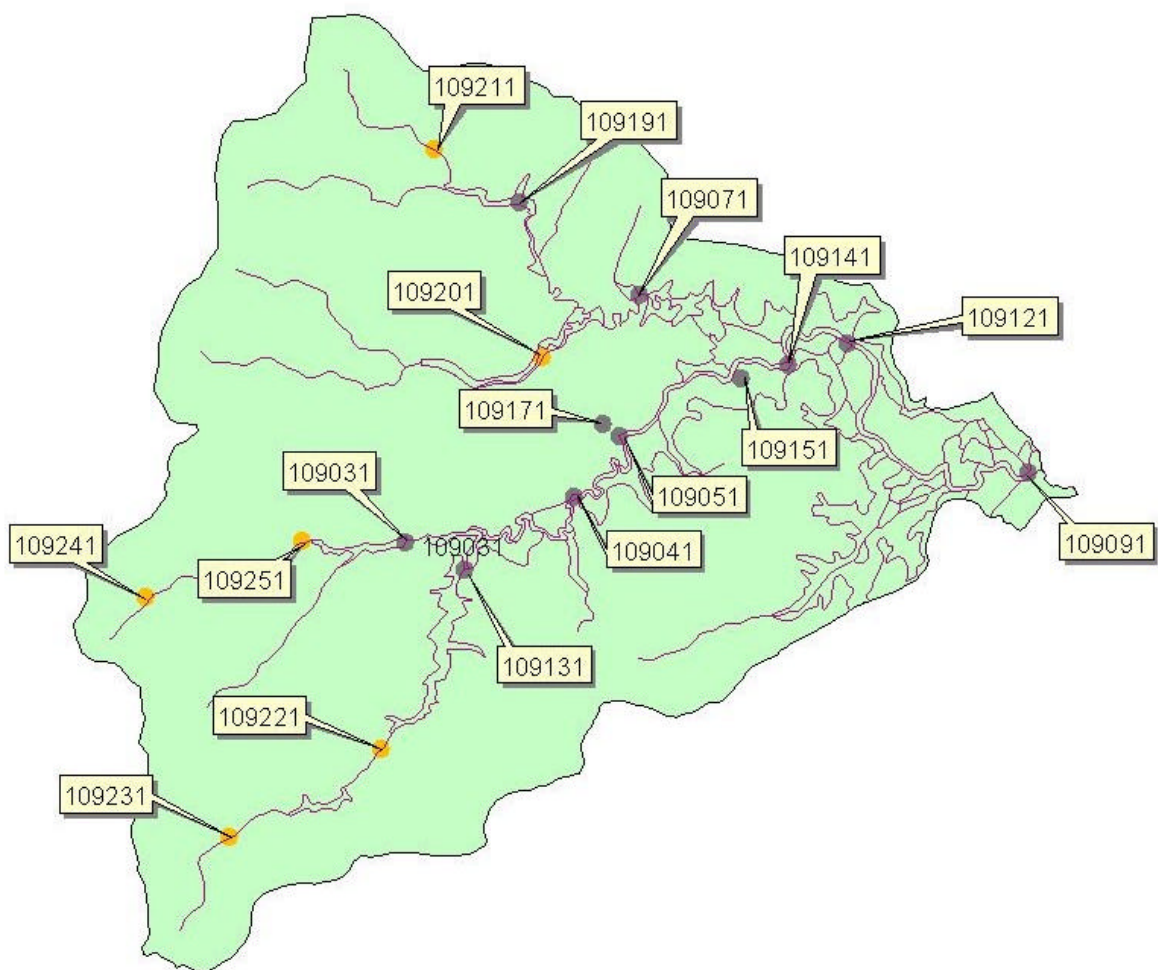


Figure 4-1 Monitoring Stations within the Appoquinimink River Watershed

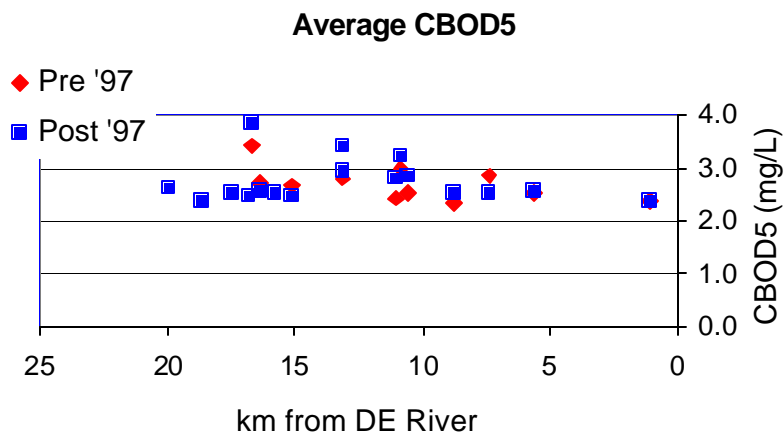
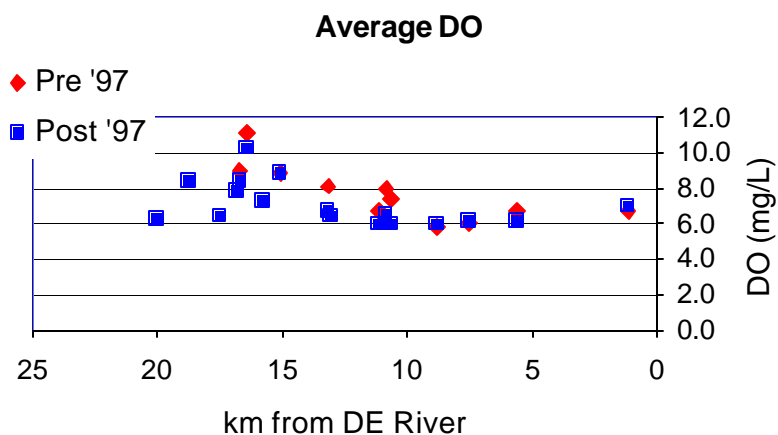
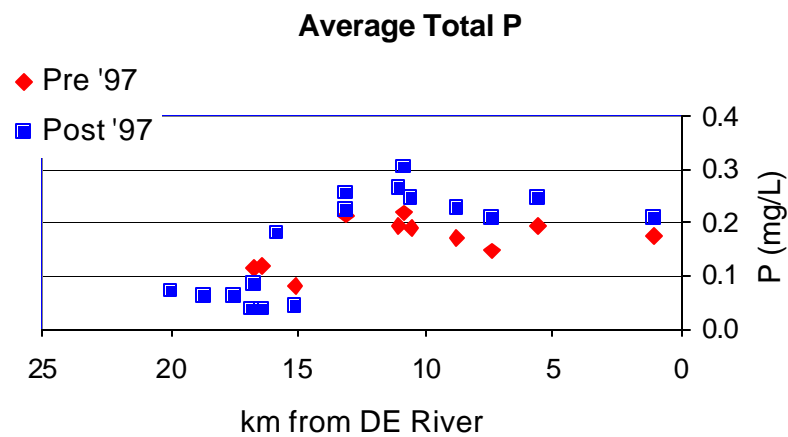
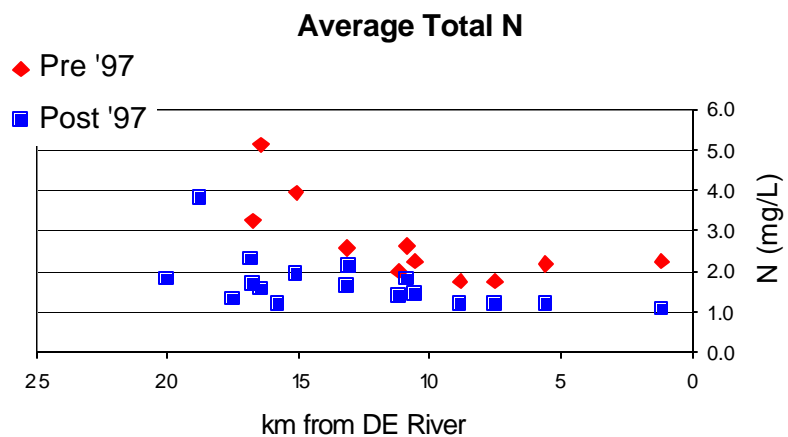


Figure 4-2 Comparison of Pre 1997 Data versus 1997-2000 Data for the Appoquinimink Watershed

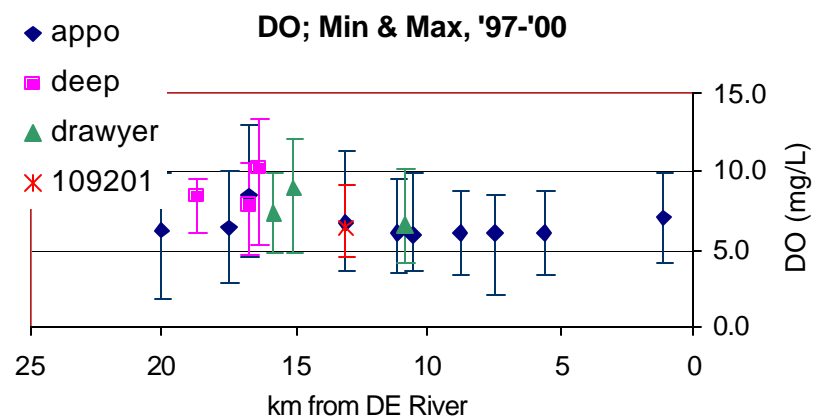
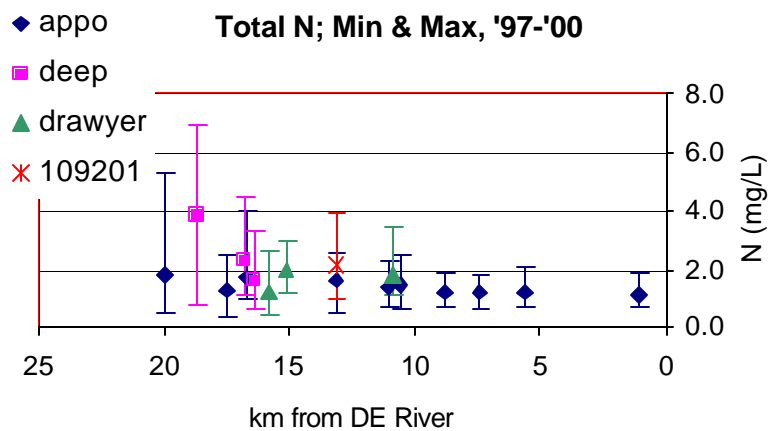
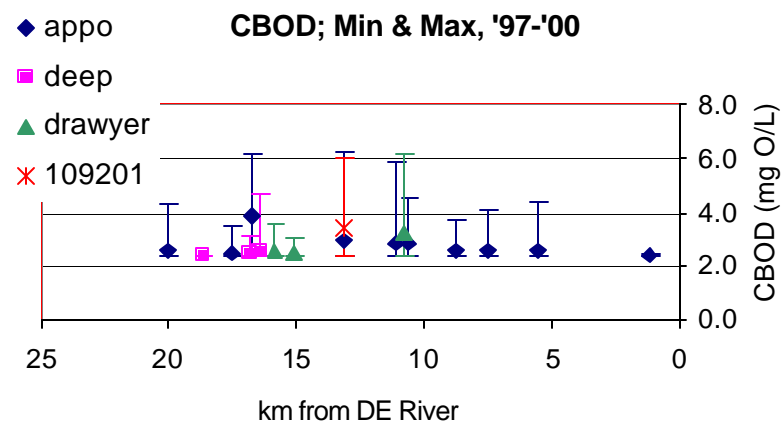
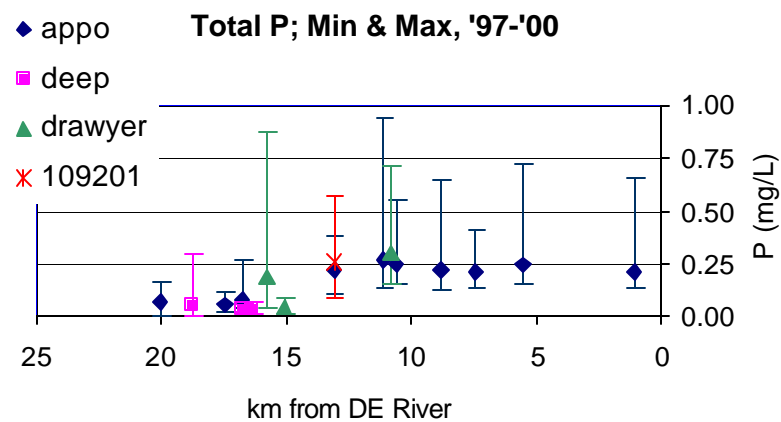


Figure 4-3 Max Min Values for the 1997-2000 Data

Table 4-1 Sensitivity Analysis Scenarios C1-C52

Scenario	Parameter Changed	Effect				
		Minimum DO mg/L	(average concentration change with respect to waspver4 run)			
			Total N mg/L	Total P mg/L	CBOD mg/L	Chl-a mg/L
C1	No PS MOT	4.04	-0.0500	-0.0087	-0.1071	-0.6361
C2	½ X FNH ₄	3.83	0	0	0	0
C3	½ X SOD1D	4.52	-0.0003	0	-0.0162	0
C4	2X SOD1D	0.74	-0.0033	0	0.0945	0
C5	2X FNH ₄	3.83	0	0	0	0
C6	½ X FPO ₄	3.83	0	0	0	0
C7	2X FPO ₄	3.83	0	0	0	0
C8	½ X SAL	3.90	0	0	-0.0014	0
C9	2X SAL	3.70	0.0001	0	0.0029	0
C10	½ X KESG	5.43	0.0754	0.0086	0.1107	9.0396
C11	2X KESG	2.99	-0.0410	-0.0032	-0.0907	-5.8927
C12	0 constant inflow			unstable		
C13	½ X constant inflow	3.83	0.0127	0.0019	-0.1267	0.2555

Scenario	Parameter Changed	Effect				
		Minimum DO mg/L	(average concentration change with respect to waspver4 run)			
			Total N mg/L	Total P mg/L	CBOD mg/L	Chl-a mg/L
C14	1½ X constant inflow	3.80	-0.0128	-0.0018	0.1293	0.2530
C15	2X constant inflow			unstable		
C16	½ X Flow, all segments	3.71	0.2225	0.0127	0.0724	3.6237
C17	2X Flow, all segments	3.85	-0.2363	-0.0168	-0.0994	-4.6343
C18	BC: ½ X NH3-N	3.85	-0.0222	0	-0.0003	0
C19	BC: 2X NH3-N	3.80	0.0457	0	0.0007	0
C20	Added MOT inflow	3.81	-0.0050	-0.0004	-0.0082	-0.0628
C21	C20 & BC: ½ X NOx-N	3.81	-0.0653	-0.0004	-0.0037	-0.0628
C22	C20 & BC: 2X NOx-N	3.82	0.1165	-0.0004	-0.0171	-0.0628
C23	C20 & BC: ½ X PO4	3.81	-0.0117	-0.0043	-0.0186	-0.7591
C24	C20 & BC: 2X PO4	3.82	0.0075	0.0074	0.0101	1.1404
C25	C20 & BC: ½ X Phyt	3.89	-0.0396	-0.0035	-0.0375	-2.6253
C26	C20 & BC: 2X Phyt	3.60	0.0614	0.0069	0.0466	4.7211

Scenario	Parameter Changed	Effect				
		Minimum DO mg/L	(average concentration change with respect to waspver4 run)			
			Total N mg/L	Total P mg/L	CBOD mg/L	Chl-a mg/L
C27	C20 & BC: ½ X CBOD	4.15	-0.0053	-0.0004	-1.3075	-0.0628
C28	C20 & BC: 2X CBOD	2.50	-0.0042	-0.0004	2.6614	-0.0628
C29	C20 & BC: ½ X Diss O2	2.67	-0.0043	-0.0004	0.0313	-0.0628
C30	C20 & BC: 10 mg/L Diss O2	4.00	-0.0055	-0.0004	-0.0292	-0.0628
C31	C20 & BC: ½ X Org-N	3.82	-0.1518	-0.0004	-0.0082	-0.0628
C32	C20 & BC: 2X Org-N	3.79	0.2829	-0.0004	-0.0081	-0.0628
C33	C20 & BC: ½ X Org-P	3.78	-0.0117	-0.0224	-0.0181	-0.7307
C34	C20 & BC: 2X Org-P	3.86	0.0086	0.0434	0.110	1.2355
C35	C20 & 7Q10, New permit MOT PS	3.95	-0.0340	-0.0063	-0.1747	-0.4657
C36	C35 & SOD values: EPA TMDL 1/98	4.76	-0.0340	-0.0063	-0.1925	-0.4657
C37	C36 & 15kg/day CBOD NPS	4.76	-0.0340	-0.0063	-0.1798	-0.4657
C38	C37 & EPA DO BC, DE river	4.90	-0.0340	-0.0063	-0.1821	-0.4657
C39	C38 & EPA initial DO conc	4.68	-0.0340	-0.0063	-0.1769	-0.4657

Scenario	Parameter Changed	Effect				
		Minimum DO mg/L	(average concentration change with respect to waspver4 run)			
			Total N mg/L	Total P mg/L	CBOD mg/L	Chl-a mg/L
C40	C39 & EPA '98 TMDL BC, DE River: NH3-N	4.60	0.0074	-0.0063	-0.1763	-0.4657
C41	C40 & EPA '98 TMDL BC, DE River: NOx-N	4.60	0.1032	-0.0063	-0.1816	-0.4657
C42	C41 & EPA '98 TMDL BC, DE River: PO4	4.62	0.1053	-0.0004	-0.1783	-0.2060
C43	C42 & EPA '98 TMDL BC, DE River: Phyt	4.30	0.1575	0.0054	-0.1416	3.7242
C44	C43 & EPA '98 TMDL BC, DE River: CBOD	2.83	0.1581	0.0054	2.0851	3.7242
C45	C44 & EPA '98 TMDL BC, DE River: Org-N	2.82	0.4229	0.0054	2.0857	3.7242
C46	C45 & EPA '98 TMDL BC, DE River: Org-P	2.83	0.4288	0.0455	2.0941	4.3146
C47	C46 & EPA '98 TMDL Group G	2.84	0.4268	0.0453	2.0907	4.1495
C48	C47 & EPA '98 TMDL initial NOx conc	2.84	0.4337	0.0453	2.0901	4.1495
C49	C48 & EPA '98 TMDL initial Phyt conc	3.11	0.3692	0.0390	2.0120	0.5417
C50	C49 & EPA '98 TMDL initial CBOD conc	2.87	0.3692	0.0390	2.3626	0.5417
C51	C50 & EPA '98 TMDL initial Org-N conc	2.87	0.3481	0.0390	2.3626	0.5417
C52	C51 & EPA '98 TMDL initial Org-P conc	2.87	0.3501	0.0432	2.3661	0.7371

5. Evaluation of Various Loading Scenarios and Proposed TMDL

The results of the water quality monitoring and modeling show that the State water quality standards and targets with regard to DO, total N and total P are not met in several segments of the Appoquinimink River and its tributaries. Therefore, reduction of pollutant loads from point and/or nonpoint sources are necessary to achieve water quality standards and targets.

To determine the optimum load-reduction scenario, the ARM1 model was adjusted to the current conditions and used as a baseline to evaluate different reduction scenarios. Table 5-1 illustrates the incorporation of the current conditions into the ARM1 model in order to develop a baseline to evaluate possible load reduction scenarios. The final baseline deviates from the original ARM1 hydver4.inp in the following ways: the updated hydver4 includes a 0.5 mgd flow from the MOT, the flow is reduced from the headwater of the Drawyer (originally 0.380 m³/s, new 0.301 m³/s), and a 0.80 m³/S flow now enters the Drawyer at section 34. Deviations from the original ARM1 waspver4.inp include the incorporation of boundary conditions reflecting the monitoring station data taken between 1997 and 2000 (SOD, chl-a, CBOD, DO, NH₃, NO_x, ON, OP, PO₄, and temperature). The new boundary condition data was incorporated individually into the runs (D series) using C38 as an initial starting point (see Appendix B for detailed scenario results). In addition to the scenarios reported, the effect of the reduction scenarios using the ARM0 model as well as unreported scenarios were also evaluated.

The baseline scenario and final reduction scenario are illustrated in Figure 5-1. The solid lines represent the Average concentrations on Julian day 199 and the dotted lines represent the corresponding baseline concentrations in the Appoquinimink River, Drawyer Creek, and Deep Creek. The final scenario brings both the total P and total N nutrient levels into compliance with DNREC's target levels and meets the State water quality standard for DO. To achieve this the proposed TMDL holds the MOT nutrient and CBOD₅ discharge levels constant at the concentrations prescribed by the 1998 EPA TMDL. In addition, the non point source reductions include a 20% reduction in PO₄, OP, ON, NH₃, and NO_x along with an 18.4% decrease in SOD. Since the flux rates of nutrients and SOD is a function of pollutant loads received by the system, it is a reasonable assumption to relate the percentage of the rate change to the percentage of load change (similar mechanism was suggested by the Army Corps of Engineers for the Inland Bays Model). The algorithm for this change can be shown as:

$$\text{Adjusted Rate} = \text{Base Rate} (1 + \text{PSR} * \text{PSF} + \text{NPSR} * \text{NPSF})$$

Where:

Base Rate = the nutrient and flux rates used in model calibration

PSR = percent change of point source load change. The PSR is positive when the load is increased and is negative when load is decreased

PSF = fraction of total load represented by point sources

NPSR = percent change of nonpoint source load change. The NPSR is positive when the load is increased and is negative when load is decreased

NPSF = fraction of total load represented by nonpoint sources

Table 5-1 Current Condition and Baseline Development Scenarios

Scenario	Scenario Description
D1	C38
D2	D1 with no NPS: auxiliary
D3	D1 with no NPS: Appo, Deep & Drawyer
D4	D1 with no NPS
D5	D1 with no NPS or MOT
D6	D1 with no nutrient load from DE River
D7	D1 with no nutrient load or chl-a from DE River
D8	D1 with oxygen addition in NPS auxiliary
D9	D1 with '98 EPA TMDL 7Q10 flows
D10	D1 with '97-'00 NH ₃ , NO _x , ON data for DE River BCs
D11	D10 with '97-'00 chl-a data for DE River BCs
D12	D11 with '97-'00 CBOD ₅ data for DE River BCs
D13	D12 with '97-'00 OP & PO ₄ data for DE River BCs
D14	D13 with '97-'00 dissolved oxygen data for DE River BCs
D15	D14 with DE River BC: 10% nutrient load reduction, 10% increase in DO
D16	D14 with KESG=3.2 in segments 1-14 (secchi depth 24")
D17	D16 with DE River BC: 20% total load reduction & 20% increase in DO
D18	D17 with NPS: Appo, Deep, Drawyer 20% total load reduction
D19	D1 with '97-'00 data, all BCs
D20	D19 with no NPS: auxiliary
D21	D19 with no NPS: Appo, Deep & Drawyer
D22	D19 with no MOT
D23	D19 with no NPS
D24	D19 with no NPS or MOT
D25	D19 with DE River BC: 10% nutrient load reduction, 10% increase in DO
D26	D19 with DE River BC: 10% increase in DO
D27	D19 with 25% NPS: Appo, Deep & Drawyer total load reduction
D28	D27 with 10% SOD reduction
D29	D19 with 25% NPS total load reduction & 10% SOD reduction
D30	D19 with 35% NPS total load reduction & 10% SOD reduction
D31	D29 with '98 EPA TMDL DE River DO BC
D32	D31 with 50% decrease in PO ₄ & OP into the Drawyer
D33	D32 with DE River BC: 10% total load reduction
D34	D32 with '98 EPA TMDL DE River BCs
D35	D32 with 15% SOD decrease instead of 10% SOD decrease
D36	D32 with 25% SOD decrease instead of 10% SOD decrease
D37	D36 with '98 EPA TMDL 7Q10

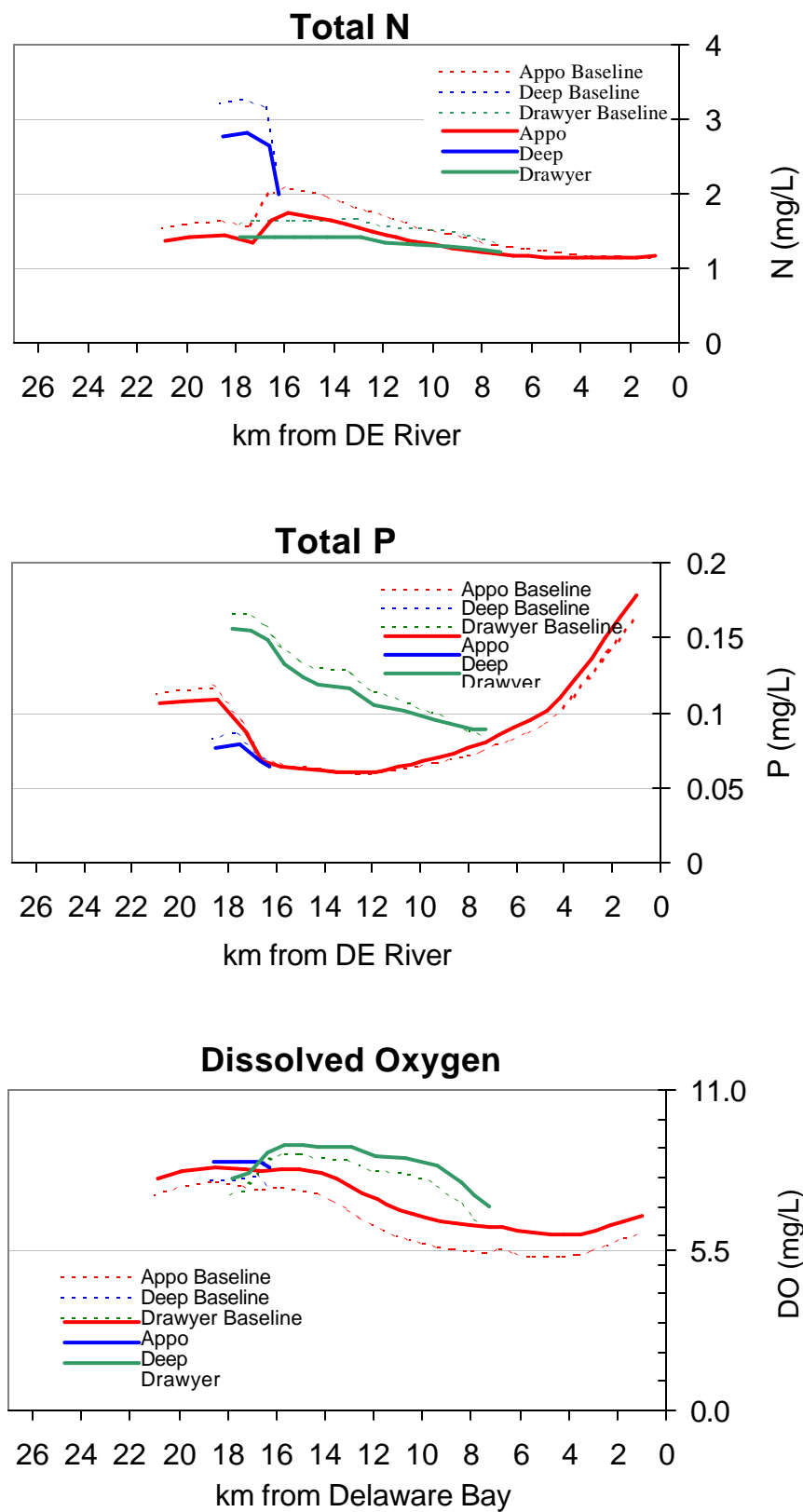


Figure 5-1 Base Line versus Final TMDL Reduction Scenario, Average Values on Day 199

Table 5-2 illustrates the proposed TMDL loads for the Appoquinimink River Watershed. The only point source (MOT) will be limited to a discharge of 10.4 lb total N per day, 2.1 lb. total P per day, and 34.8 lb CBOD₅ per day with a flow rate not to exceed 0.5 mgd. The proposed nonpoint source loads are 334.1 lb total N per day and 18.0 total P per day. The total TMDL loads are 344.5 lb total N per day, 20.1 lb total P per day, and 34.8 lb CBOD₅ per day.

Table 5-2 Proposed TMDL Loads for the Appoquinimink Watershed

Source	Flow (mgd)	Total N (lb/d)	Total P (lb/d)	CBOD₅ (lb/d)
Waste Load Allocation (WLA) for Point Source: MOT	0.5	10.4	2.1	34.8
Load Allocation (LA) for Nonpoint Sources	-	334.1	18.0	-
Proposed TMDL Total Loads	-	344.5	20.1	34.8

6. Discussion of Regulatory Requirements for TMDLs

Federal regulations at 40 CFR Section 130 require that TMDLs must meet the following eight minimum regulatory requirements:

1. The TMDLs must be designed to achieve applicable water quality standards
2. The TMDLs must include a total allowable load as well as individual waste load allocations for point sources and load allocations for nonpoint sources
3. The TMDLs must consider the impact of background pollutants
4. The TMDL must consider critical environmental conditions
5. The TMDLs must consider seasonal variations
6. The TMDLs must include a margin of safety
7. The TMDLs must have been subject to public participation
8. There should be a reasonable assurance that the TMDLs can be met

1. The Proposed Appoquinimink River Watershed TMDL is designed to achieve applicable water quality standards.

The model analysis indicates that after the proposed reductions are met, the minimum DO level in any portion of the Appoquinimink will not fall below the 5.5 mg/L standard.

With regard to nutrients, model analysis indicates that the target levels (1.0-3.0 mg/L total N, 0.1-0.2 mg/L total P) will be obtained after the proposed reductions are met.

2. The Proposed Appoquinimink River Watershed TMDL includes a total allowable load as well as individual waste load allocations for point sources and load allocations for nonpoint sources.

Table 5-2 lists the proposed WLA and LA for the Appoquinimink River Watershed. The total WLA is 10.4 lb/d total N, 2.1 lb/day total P, and 34.8 lb/d CBOD₅. The LA is 334.1 lb/d total N and 18.0 lb/d total P.

3. The proposed Appoquinimink River TMDL considers the impact of background pollutants.

The proposed TMDL is based upon a calibrated and verified hydrodynamic and water quality model of the Appoquinimink River and its tributaries, lakes, and ponds. The model was developed using an extensive water quality and hydrological database. The water quality and hydrological database included headwater streams representing background conditions for nutrients and other pollutants. Therefore, it can be concluded that the impact of background pollutants are considered in the proposed Appoquinimink River Watershed TMDL.

4. The proposed Appoquinimink River Watershed TMDL considers critical environmental conditions

The proposed TMDL was established based on the calculated 7Q10 (Section 3) and the ambient conditions on Julian day 199 when the ambient air and water temperatures are relatively high. The average salinity in the section of the Appoquinimink River between the confluence of the Delaware River and the intersection with Drawer Creek is above the salt water salinity standard of 5 ppt. but because the minimum is below the 5 ppt level, it is considered fresh water. The results of the water quality modeling analysis have shown that considering the above design conditions, State water quality standards and targets are still met within the Appoquinimink River Watershed. Therefore, it can be concluded that consideration of critical environmental conditions was incorporated in the Appoquinimink River Watershed TMDL analysis.

5. The proposed Appoquinimink River Watershed TMDL considers seasonal variations.

The model used to represent the watershed was calibrated for the period of August 11 through October 14, 1991 and was validated for the period of May 10 through July 25, 1991. The above calibration and verification periods included different seasons with varying environmental conditions. Therefore, it can be concluded that consideration of seasonal variations was incorporated in the Appoquinimink River Watershed TMDL analysis.

6. The proposed Appoquinimink River Watershed TMDL considers a margin of Safety.

EPA's technical guidance allows consideration of a margin of safety as implicit or as explicit. An implicit margin of safety is when conservative assumptions are considered for model development and TMDL establishment. An explicit margin of safety is when a specified percentage of assimilative capacity is kept unassigned to account for uncertainties, lack of sufficient data, or future growth.

An implicit margin of safety has been considered for establishing the proposed Appoquinimink River Watershed TMDL. The ARM1 model is calibrated using conservative assumptions regarding reaction rates, pollutant loads, and other environmental conditions. Consideration of these conservative assumptions contributes to the implicit margin of safety. In addition, the proposed TMDL considers several critical conditions such as 7Q10 flows, high ambient and water temperatures, high salinity in segments up to the confluence with the Delaware river, and MOT discharges at maximum permitted levels. Since the possibility of occurrence of all these critical conditions at the same time is rare, the above consideration contributes to the implicit margin of safety. Therefore, it can be concluded that an implicit margin of safety has been considered for this TMDL analysis.

7.0 The proposed Appoquinimink River Watershed TMDL has been subject to public participation.

The EPA held a public hearing prior to the adoption of the 1998 TMDL covering the mainstem of the Appoquinimink river. During the adoption period of the '98 TMDL, DNREC and the public had an opportunity to present comments.

Another important public participation activity regarding this TMDL was the formation of the Appoquinimink Tributary Action Team last year. The Tributary Action Team, made up of concerned citizens and other affected parties within the watershed, has met several times and will assist the DNREC in developing pollution control strategies (PCS) to implement the requirements of the proposed Appoquinimink River Watershed TMDL.

In addition to the public participation and stakeholder involvement mentioned above, a public workshop and public hearing has been scheduled for December 5, 2001 to present the proposed Appoquinimink River Watershed TMDL to the general public and receive comments prior to formal adoption of the TMDL regulation.

8.0 There should be a reasonable assurance that the proposed Appoquinimink River Watershed TMDL can be met.

The proposed Appoquinimink River Watershed TMDL considers the reduction of nutrients and oxygen consuming pollutants (CBOD) from point and nonpoint sources. The magnitude of load reductions suggested by the proposed TMDL is in line with the current TMDL and is technically feasible and financially affordable. Following the adoption of the TMDL, the Appoquinimink River Tributary Action Team will assist the Department in developing a PCS to implement the requirements of the Appoquinimink River Watershed TMDL Regulation. The DNREC is planning to finalize and adopt the Appoquinimink River PCS within one year after formal adoption of the TMDL Regulation.

7. REFERENCES

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